NUCLEAR CRASH

The U.S. Economy After Small Nuclear Attacks

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INTRODUCTION

The effects of a nuclear attack on a country's society and economy have been the subject of numerous studies based on data from the nuclear bombs used against Hiroshima and Nagasaki, from nuclear tests, and from conventional-bomb damage data [1]. Even though these studies have focused on quantitative calculations of the physical damage and have presented only qualitative extrapolations of the effects of this damage on the fate of the survivors, they were instrumental in establishing the fact that a nuclear exchange between two warring nations would result in tremendous devastation. From this fact comes the conclusion that the only actual use for nuclear explosives is to maintain deterrence, that is, to insure that a nuclear opponent does not use his nuclear arsenal against you.

Most of these studies have had one of two purposes: either to show that a nuclear war is unwinnable; or to guide military planners in determining the size of their country's nuclear arsenal. Even though many studies indicated that deterrence could be supported by a relatively small nuclear arsenal, the total number of nuclear weapons deployed by the U.S. and the Soviet Union now approaches 50,000. Dissatisfaction with this development has prompted two reactions in this country. The first is a move to limit the nuclear explosives in each arsenal to the number that would securely deter an opponent -- that is, towards reduction of the number of nuclear explosives. The other is to try to develop a defensive system that would effectively protect the society and economy of the U.S. regardless of the number of nuclear weapons deployed by the Soviet Union.

Indeed, both policies are in the forefront of the national security debate right now.

The Reykjavik summit indicated that both nuclear superpowers are willing to lower the number of nuclear explosives in their arsenals. Each side would presumably want to retain enough weapons to deter the other side from attacking, enough weapons to inflict a so-called unaccepatable level of damage on the other side. On the other hand, the decision as to whether to pursue the Strategic Defense Initiative could well depend on judgments about how successful that defense will be in limiting a nuclear attack to fewer than the number of nuclear weapons that would cause the collapse of our society and economy. Both policies imply an estimate of the minimum number of nuclear weapons that would inflict unacceptable damage on our country. Physical damage that would collapse a country's economy for the indefinite future would, beyond doubt, be considered unacceptable even by the most determined and sanguine political leadership.

Studies done under government contract in the U.S. have until very recently shown that the U.S. economy can survive a limited nuclear attack. For example, a 1973 report [2] on an input-ouput computer model simulation of the economy predicted complete economic recovery from a nuclear attack within a decade and a half -- regardless of the attack size, which varied from 4% to 20% of the Soviet arsenal.

But very different results are reached by a 1980 systems dynamics computer model simulation of the post-attack U.S. economy that was commissioned by the Federal Emergency Management Agency (FEMA). The new FEMA model predicts the collapse of the U.S. economy following an attack much smaller than those SRI studied. To rebuild the economy to anything near its previous levels would take many decades.

If different models lead to different conclusions, how can one decide which one is best approximating the grim post-attack reality. We will examine both the SRI and FEMA models and show how the former was bound to give misleading results, while the latter was specifically designed to minimize or avoid many problems inherent in previous computer models of the post-attack economy.

Previous models were designed to operate within historical bounds, with the economy in equilibrium and so were unrealistic in their representation of the post-attack economy, which could very well be out of equilibrium for extended periods of time. Previous models have tended to be simple, linear, growth models that reproduce the historical behavior of the U.S. economy -- sustained growth -- almost immediately after much larger attacks than we consider here. The FEMA model, on the other hand, is designed to handle both equilibrium and non-equilibrium conditions. It is composed of hundreds of non-linear, recursive equations. And while these equations reflect the historical performance of the economy, they are also designed to reflect specific actions taken by economic decision-makers (consumers, government officials, and corporate exectutives). Therefore, while the FEMA model can reproduce historical patterns, it is not 'forced' to.

The technique the FEMA models uses, System Dynamics, is more interactive, more dynamic, and more flexible than methods previously used for simulations of the post-attack economy. In addition, we have based our analyses on 1) the latest, most realistic estimates of the effects of nuclear weapons, 2) a detailed study of the distribution of key U.S. industries, and 3) an extensive Census Bureau database of U.S. population and manufacturing capacity. Nevertheless, the FEMA model is only a computer model, and while it may be more rigorous than the 'mental' models we all use to anticipate the behavior of the world, its results should be viewed cautiously. For instance, the FEMA model is not capable of predicting precise quantitative results, such as the exact level of GNP 20 years after an attack. The results it most reliably produces are qualitative trends, such as the inability of the GNP to recover for decades.

It deserves mention that the computer model used here is not exactly the same as that used in the FEMA report approved for public release in November 1980. Over the last several years, some of the original authors, as well as our group, have worked to fix some of the errors in that program, and have improved its ability to model the U.S. economy.

This report presents the preliminary results of a study that explores the predictive capability of the FEMA simulation program and the degree to which computer modeling can provide reliable predictions of the behavior of the U.S. economy after a nuclear attack. The study was undertaken with several purposes in mind:

A. To determine whether the discrepancy between older static simulation models and the FEMA model is significant in the context of decisions about the nuclear policy of the country.

B. To determine the minimum number of nuclear explosives that would create a perturbation severe enough to collapse the U.S. economy; that is, the number that would be an unquestionable deterrent in the hands of the Soviets. This number, augmented to allow for certainty of delivery, could then become a guideline for future nuclear arms limitation negotiations. For instance, both sides could reduce to number that would assure them of the ability to deliver the nuclear explosives that would collapse the other side's economy. (FEMA has commissioned a similar computer simulation of the Soviet economy.)

C. To provide a measurement for the efficiency required of a strategic defensive shield designed to permit the U.S. economy to survive a full Soviet nuclear attack.

We have used the FEMA program that simulates the U.S. economy to examine the results of small nuclear attacks that would collapse the U.S. economy. We were looking for the most effective "bottleneck" mechanisms for collapse, and as a consequence we have focused particular attention on liquid fossil fuels. Transportation, energy production, and many crucial industry products depend on liquid fuels. We have found that the shock of denying these resources to the U.S. for even a relatively short period of time disintegrates the economy. This rapid economic deterioration -- the "nuclear crash" -- could mean that within months of an attack most of the population would starve to death and that the survivors would be reduced to near-medieval levels of existence for decades.

We find that these predictions are not particularly sensitive to the destructiveness assumed for individual attacking weapons. We demonstrate that even using consistently conservative assumptions -- which lead to overestimates of the likelihood of a U.S. national economic recovery -- an attack consisting of as little as 1% to 2% of the Soviet nuclear arsenal could cause a complete and long-lasting economic crash in the United

States.

At every turn of the research our assumptions, introduced into the computer program either explicitly — as initial values of variables — or implicitly, have been uniformly conservative. We have tested the sensitivity of the computer model over a large range of assumptions, and we present the results of simulation in only those cases when we have biased the assumptions towards recovery of the economy. Yet the perturbations caused by the small, bottlenecking attack scenarios we tested consistently demonstrate the vulnerability of the U.S. economy to a Soviet attack that would not exceed 1% to 2% of their nuclear arsenal.

It bears repeating that the FEMA program we used cannot simulate with high analytical precision the effects of the selective destruction of very small though crucial sectors of the U.S. economy — destruction which we believe would drastically affect the economy. Moreover, limitations exist in any computer model of the economy (as we discuss in Chapter Three), and so our results must be read as suggestive rather than definitive. Real nuclear attacks would doubtless be much worse than the FEMA model indicates.

The report consists of five chapters and two appendices. Chapter One reviews the most recent information regarding the effects of nuclear explosives on civilian targets. Consistent with our conservative approach we have incorporated into the simulation only two destructive effects, blast and heat, ignoring the effects of the nuclear electromagnetic pulse (EMP) and of delayed radioactive fallout on the U.S. economy. We believe that EMP would in fact have devastating effects on communications and other electronic equipment, including computers, and that fallout would drastically limit the use of undamaged industrial-production capacity and food-producing farm lands, and consequently their inclusion would exacerbate economic disfunction. But we could not incorporate these effects into the simulation program in a way that would lead to reliable predictions of their impact on the evolution of the economy after the attack.

Chapter Two discusses the U.S. economy in terms of its vulnerability to nuclear attack. We examine the concentration of key industries, and the importance of energy (particularly liquid fuels) to the transportation sector and the rest of the economy.

In Chapter Three we discuss methodology. We explored the reliability and practical limits of the computer simulation technique we have used, System Dynamics, its strengths and its weaknesses. We give the detailed features of the FEMA program, explain the tests we have performed, the modifications we have made in the program, and the overall confidence one can have in the results of simulation techniques.

In Chapter Four we present the results of sensitivity tests we performed to determine the effect of several key economic variables on the behavior of the economy and whether the program results were consistent with common sense expectations.

In Chapter Five, we consider the effects of three different attack scenarios on the U.S. economy. The first is an attack which destroys 60% of the population and 40% of the industry, which we call the 60/40 Attack. The smallest of the three attacks, the Counter-Energy Attack, destroys only commercial ports and the refining and storage facilities for liquid fossil fuels. The third attack destroys, in addition to the fuel facilities, some key manufacturing sectors such as electronics, primary metals production, and heavy machines. This we call the Counter-Energy

Counter-Industry attack. We present the results in the form of graphs, with some discussion.

In the two appendices we give information in greater detail about one of the tests we ran (I) and we list the targets in counter-energy attack (II).

Because of the very large number of assumptions we have necessarily made in exploring the effects of these attacks, two things must be borne firmly in mind when reading this report. First, that the results are uniformly *optimistic*, erring towards the best-case view at every point of choice, and second, that it is *trends* rather than absolute values that one should focus on in reading the report.

CHAPTER ONE

EFFECTS OF NUCLEAR WEAPONS

The single most important factor in any analysis of the effect of nuclear war on the economy is the almost incomprehensibly destructive nature of nuclear weapons. In this chapter we will give a brief, quantitative description of the effects of nuclear weapons followed by a qualitative description of the two small Soviet nuclear attacks on U.S. cities that will be used throughout this report as standard test cases.

Typical weapons in the Soviet Union's arsenal are the 500- to 550-kiloton warheads the Soviets have on many of their SS-18 and SS-19 land-based missiles. The 550-kiloton weapons release the energy equivalent of 550 thousand tons of TNT and are about 40 times the yield of the bomb that levelled Hiroshima. At a distance of 3.6 miles from a 550-kiloton air-burst, the winds of over 160 miles an hour are capable of blowing down virtually all trees and the blast wave overpressure of 5 psi (pounds per square inch) will destroy most houses.

In what has become a standard calculation, the expected damage from this large detonation has been extrapolated from the damage done to Hiroshima by the single bomb that was dropped on it in August, 1945. This traditional extrapolation is based primarily on the blast effects: it is assumed that the same damage to buildings and the same percentage of people killed and injured near the 5-psi contour at Hiroshima will occur near the 5-psi contour of a much larger weapon air-burst over a modern city. The overall damage level is calculated by carrying out similar extrapolations for the other blast contours. To avoid all of this intricate calculation, the Office of Technology Assesment (OTA) suggests using a cookie-cutter approach in which it is assumed that everyone within the 5-psi contour is killed and everyone outside the 5-psi contour survives [1] (a similar approach is often taken to calculate the destruction of buildings).

We shall use this approximation as our most conservative estimate of the effects of nuclear weapons on both people and buildings in our attacks. It is, however, important to understand why this approach is flawed: extrapolating damage from blast effects in Hiroshima seriously underestimates the effects of nuclear weapons.

The extrapolation depends crucially on the assumption that the blast destruction in the case of Hiroshima -- a single, small (14-kiloton) weapon detonated in the air -- is representative of the actual destruction that would take place in a nuclear war today. Yet there are some important differences. Hiroshima involved a weapon detonated in the air. Since air bursts generate much less radioactive fallout than bombs detonated on the ground, at Hiroshima there was relatively little lingering radiation from fallout, and so the city was able to receive outside help almost immediately. This kind of help seems unlikely in a modern war, both because devastation would be widespread, and because targeted areas might be deliberately made lethal to would-be help by detonating weapons on the ground. Moreover, targeted regions are likely to receive multiple weapons, creating synergistic effects greater than the sum of the effects of individual weapons. For instance, a building weakened by one blast wave might be leveled by a second blast wave, even though neither blast wave by itself would have been sufficient to topple the building.

But perhaps the greatest problem with an extraploation from Hiroshima on the basis of blast effects alone is that such an approximation does not take into account the fact that the thermal effects of nuclear weapons increase faster with increasing weapon yield than the blast effects do. For the 14-kiloton bomb dropped on Hiroshima, the 5-psi contour occurred at about one mile, where some 12 calories of heat per square centimeter were deposited. This heat would cause third-degree burns to exposed skin and would ignite highly combustible materials and perhaps dry leaves, newspapers, and interior curtains. At this distance, the probability of being killed in Hiroshima was about 30%.

For the 550-kiloton bomb, the 5-psi contour occurs at 3.6 miles -- where about 30 calories per square centimeter are deposited, on a clear day [2]. This is more than twice the heat needed to cause third-degree burns to exposed skin and it is sufficient to ignite standard building materials and clothing. Clearly, far fewer people would survive at the 5-psi contour of the 550-kiloton weapon than survived the 5-psi contour of the Hiroshima bomb -- even if there is no mass fire.

Yet, according to work done by Stanford's Theodore Postol [3] the likelihood of a mass fire extending far beyond the 5-psi contour is great, even in lightly built-up cities. Postol suggests that we abandon the extrapolation on the basis of blast effects, and instead recommends that we extrapolate on the basis of thermal effects. In Postol's model, superfires are likely wherever 10 or more calories per square centimeter are deposited (Hiroshima itself experienced a firestorm within the 10-calorie contour). Postol suggests substituting the thermal 10-calorie contour for the blast-related 5-psi contour as the meaningful limit of destruction (for large weapons).

A single nuclear detonation can smash buildings, destroy gas and water mains, scatter debris, and ignite thousands of fires. Firestorms are created when these relatively small fires coalesce into one superfire. Firestorms can generate ground winds of 30 to 60 miles an hour, ground temperatures well above the boiling point of water, and tremendous amounts of noxious gases such as carbon monoxide, hydrogen cyanide, and sulphur dioxide. The chances of survival under such conditions are slim. This is especially true because injured survivors trapped in a superfire might have to travel a great distance to escape it, particularly after large detonations. For the Hiroshima bomb, the distance between the region within the superfire where people had much chance of surviving the initial blast and the region outside the superfire was under half a mile. For a 550-kiloton bomb, however, this "escape" distance is over 3 miles (in the case of a multiple detonation, there may be no possible escape distance).

There is uncertainty about exactly what kind of mass fires will develop after a nuclear detonation starts thousands of fires inside and outside of the 10-calorie contour. Because of this uncertainty, Postol suggests another cookie-cutter approach, in which few people and buildings survive within this 10-calorie contour, and few people are killed and few buildings are damaged outside this contour. For a 550-kiloton weapon, the 10-calorie contour extends out to 6 miles -- a 100-square-mile region of devastation that is 2.5 times larger than the 40 square miles within the 5-psi contour!

Although we think this approximation is eminently reasonable, in this report we will use a far more conservative one as our baseline case. First, we will assume that the 5-psi contour is the limit for the destruction of buildings. Second, we will assume that everyone within the 5-psi contour is killed (which is the OTA's cookie-cutter approach). In addition, we will assume that between the 5-psi contour (at 3.6 miles) and the 10-calorie contour (at 6 miles), half the people are killed and half the people are injured. Essentially, these assumptions are a compromise: they do take into account the increase in expected casualty rates due to thermal effects, but they do not really anticipate the occurrence of superfires.

These assumptions are also conservative in that they do not take into account the effects of ground bursts or multiple detonations. A 550-kiloton groundburst covers more than 1000 square miles with the lethal dose of radiation, and it covers more than 2000 square miles with enough radiation to increase the mortality of burn injuries by almost a factor of 8. Many targets in even a very small nuclear war are likely to be bombarded with several weapons, in which multiple bursts, multiple thermal effects, and radiation have tremendous synergistic effects. All of the scenarios we consider involve multiple bursts in many major cities, making mass fires more likely and survival less likely.

Nevertheless, we will stick with the conservative assumptions outlined above. Let us look at what they mean in a very crude sense. These assumptions result in 100% fatalities within 40 square miles and 50% fatalities and 50% injuries within another 60 square miles. If the population is distributed evenly, then in the total 100 square miles, there will be 70% fatalities and 30% injuries, from a 550-kiloton air burst. Some 130 million Americans are concentrated in urban areas on about 17,000 square miles [4]. In a rough approximation, 170 550-kiloton weapons will cause 70% fatalities and 30% injuries over this entire area (170 times 100 square miles equals 17,000 square miles). In this calculation, 2% of the Soviet Union's arsenal would kill 90 million Americans and injure another 40 million. In a real attack, it might take more weapons, but then again, the weapons are probably more deadly than we have assumed, especially if the Soviets ground-burst some of them.

In addition, it should be mentioned that the percentage of the Soviet Union's arsenal used in this small attack is calculated in the traditional way, using equivalent megatons. The area enclosed within the blast contour increases as the two-thirds power of the yield, so that a one-megaton bomb, which has 1000 times the yield of a one-kiloton bomb, does only 100 times as much blast damage. The destructive force of either superpower's nuclear arsenals is usually calculated by taking the yield of each weapon in megatons, raising that number to the two-thirds power, and then adding up the modified numbers. If the blast wave were in fact responsible for most destruction, this would be a reasonable approximation. But in the case where heat and fires do most of the damage -- as is probably the case for attacks on cities -- a better approximation is just to add the yields of the weapons together, because the area exposed to a given thermal effect rises more nearly linearly with yield. If we call these megatons "absolute" megatons, then the attack described in the previous paragraph, rather than using 2% of the Soviet's equivalent megatons, instead uses only about 1.5% of their absolute megatons [5]. This is not a big difference, but absolute megatons have the advantage of simplicity as opposed to the arcane and jargony equivalent megatons -- a term often used to obscure larger issues. Nevertheless, to keep our calculations conservative, we will in general describe the size of Soviet attacks in the traditional manner, using equivalent megatons; but to show how this overestimates the size of the attack, we will occasionally also give the absolute megaton figures.

Before going further, one more special effect of nuclear weapons deserves attention. A single multi-megaton detonation 100 miles above the central United States would create a tremendous voltage surge (an electromagentic pulse or EMP) over the entire nation that could very well damage, destroy or disrupt for varying periods of time all electric circuitry including computer systems and telephone systems. Government studies say that the nation's electricity grid should not be relied on for power after a nuclear attack [6].

BASIC ATTACK SCENARIOS

The rest of this chapter will be devoted to discussing, qualitatively, the Soviet attack scenarios -- and their aftermaths -- that we will be using in this report. This qualitative discussion will serve as a rough physical check on the "reasonableness" of the more quantitative results of running these scenarios through the FEMA computer model. Succeeding chapters will describe the scenarios in greater detail (targets, number and yield of weapons per target), and will also describe the results of running the FEMA computer model with the attack scenarios as inputs.

In this report, we will consider two basic attacks. The first is one designed to kill or injure about 60% of the American people and destroy about 40% of its industry directly. This 60/40 attack is a slight modification of an attack described by Arthur Katz in his book Life After Nuclear War [7]. The second is a much smaller attack specifically designed to collapse the U.S. economy by drastically curtailing energy production.

This will be called the counter-energy attack.

The 60/40 Attack

The 60/40 attack uses about 6.5% of the Soviets' equivalent megatonnage, or 390 equivalent megatons, but only about 5% of their absolute megatons. The attack consists of about 500 550-kiloton weapons targeted against the 70 or so largest U.S. cities, and a few hundred 100-kiloton weapons targeted against key industries such as steel production and petroleum refining.

These weapons devastate most of the urban area of the United States, and so the immediate casualties approach 110 to 130 million people. In the 60/40 attack, virtually all of the area of the 100 or so largest cities and their suburbs is contained within the 10-calorie contour of at least one weapon. This attack is so large that New York City gets 60 nuclear weapons, Los Angeles and Chicago 40, Boston 17, St. Louis 16, Milwaukee 10, Dallas 6, and Akron, Ohio 5. For cities targeted with several weapons, the areas between weapons might receive four blast waves of about 4 psi and four thermal pulses of about 25 calories per square centimeter. There is such overkill in this attack that if some of the Soviet weapons were to prove unreliable and fail to work, the physical damage would not be appreciably reduced.

With 60 weapons targeted on New York City, Manhattan could easily be covered by 10 to 20 psi in order to level it, and three airports -- Newark, La Guardia, and Kennedy — could be turned into radioactive craters with direct ground-bursting attacks (The main physical difference that would occur in this attack if some fraction of the weapons, say one-third, were detonated on the ground instead of in the air would be that most of the major cities would be rendered uninhabitable for a long time by radiation).

Any survivors of the direct attack in the cities would very likely be injured, with little chance of escaping any nearby fires. Since medical personnel tend to be concentrated in cities, probably some 75% to 95% of the nation's doctors will themselves be killed or severely injured by this attack. Without much food, medical attention, or fuel, the prospects of survival for even the uninjured survivors are not very good. Outside help will be extremely unlikely, since the major ports and airports in the country will destroyed (and perhaps irradiated), and the rest of the world may itself be struggling as much as the United States.

Thus, very soon after the attack, most injured people would probably have died from some combination of fires and lack of food, shelter, or medical attention. Within a week, the overall fatalities would probably exceed 65% of the American population -- perhaps 160 million people.

The attack would physically destroy about 40% of the nation's manufacturing capacity, although as much as 70% or more would probably be subjected to some combination of blast, heat and fires.

The 60/40 attack we are considering is, however, very unbalanced in that it specifically targets certain key "bottleneck" industries that the rest of the economy relies on. Petroleum refining, iron and steel works, nonferrous metals smelting and refining, engines and turbines, electrical distribution products, and drug manufacturing are reduced to about 2% to 3% of their pre-attack level.

The result of the loss of the nation's petroleum refining capability is particularly decisive. Even if the nation were still importing fuel, it is very likely to be unrefined fuel that we receive, since under a third of imported petroleum is refined, currently. But with every major port destroyed and perhaps irradiated, and the rest of the world struggling to avoid collapse after the devastation of the United States, imports are very unlikely. Several additional Soviet weapons launched against Mexico and Canada would render them unable to help America. The Alaska pipeline and the strategic petroleum reserves are also easy targets for nuclear weapons.

Since almost all of the fuel used in transportation is derived from petroleum (and most of the rest is derived from natural gas and electricity, which would be equally unavailable after the attack), transportation would grind to a stop, with catastrophic consequences to all surviving elements of the economy, especially food distribution. Stores of gasoline would be very scarce. Massachussetts, for instance, loses 90% of its gasoline in the attack. Attempting to rebuild the refineries would be time-consuming enough without petroleum and steel, but it would be even more difficult without transportation.

Thus, it would be reasonable to expect that the FEMA computer model should show economic collapse following this 60/40 attack. It would also be reasonable to expect that a much smaller attack could have a similar effect. Indeed, more than half of the weapons dropped on the major cities in the 60/40 attack are probably superfluous. But more significantly, if energy facilities rather than the major cities are the primary targets, the effect on the economy seems likely to be just as catastrophic.

Counter-Energy Attacks

For this reason, the second basic attack we will consider in this report is one directed primarily against the energy sector of the U.S.

economy. The targets in this "energy" attack include some 95% of the United States' petroleum refining capacity, as well as the strategic petroleum reserve, and key petroleum and natural gas pipeline nodes. To reduce imports to a trickle, all of the nation's ports are also targeted. As in the larger attack, transportation would grind to a standstill.

The energy attack requires about 240 weapons -- a mixture of 550-kiloton and 200-kiloton weapons -- that make up under 2% of the Soviet Union's equivalent megatons (but only 1% of its absolute megatons). From Anchorage to Miami, many of the targets of this attack lie in major cities across the nation -- even though energy facilities, and not population centers, are the targets. Of the twenty-five largest cities in the United States, all but seven receive one or more weapons. New York city suffers two nuclear bombs, Los Angeles six, Chicago four, Philadelphia three, Houston three and Seattle two. Detroit, San Francisco, Boston, St. Louis, Pittsburgh, Minneapolis, Cleveland, San Diego and Denver are each targeted with a weapon. One hundred weapons altogether fall on Texas, Louisiana, California, Oklahoma, and Mississippi: these states refine oil and contain many ports and oil storage terminals. Also heavily targeted for their port and refining facilities are Florida, Illinios, New York, and Pennsylvania. In fact, almost every state is targeted in this small attack, devastating a total of 481 cities, towns, and suburbs [8]. With every significant port in the United States destroyed, it would become extremely difficult to import anything and practically impossible to import those commodities that require special port facilities -- such as petroleum.

The basic energy attack uses about one-third the number of weapons that the 60/40 attack uses, and would result in perhaps 20 million immediate deaths and 5 million injured [9]. Nearly 40 million live in the targeted cities and towns, making it very likely that another 15 million would not be able to escape the immediate effects of the attack. This could include threats to the health of survivors, from contamination (a result of fallout, toxic leaks, and decaying corpses) and from a lack of medical care and food. Many additional problems would immediately result from the collapse of local government and infrastructure. In both this and the 60/40 attack scenario, the lack of energy and transportation means that it is very possible that a significant fraction of the survivors would starve to death.

In order to examine the effects of destroying many of the resources required to rebuild the economy, particularly energy facilites and others destroyed by the attack, we will also consider slightly larger versions of the basic energy attack. In these scenarios, which we label the "Counter-Energy Counter-Industry" attacks, we target a few more bottlenecking industries such as primary iron, steel and nonferrous metals production, semiconductor manufacturing and engines, turbines, motors and generators manufacturing. The loss of most of the nation's capacity to produce these items could make rebuilding petroleum refineries even more difficult and further prolong recovery. Yet fewer than 100 extra weapons could accomplish this, bringing the total attack size to just over 2% of the Soviet's equivalent megatonnage. Close to 30 million Americans would die immediately and nearly 7 million would be injured. The additional weapons would fall on major cities, including Los Angeles, San Jose, Phoenix, Detroit, Newark, Pittsburgh, Houston and Milwaukee. The states most heavily targeted in this attack are those that contain a high concentration of all types of industry: Pennsylvania, Ohio, California, Illinois, Michigan, New York and Indiana. Since this attack combines the negative effects of losing key primary and secondary industries with the removal of transportation capacity through the loss of petroleum, the effects of the attack can only be worse than the already calamitous consequences of the energy attack.

In conclusion, then, it is not surprising that the FEMA computer model indicates the U.S. economy is devastated by all of the attacks we consider. This will become even clearer as we turn to a more detailed discussion of the vulnerability of the national economy to attack.

CHAPTER TWO

THE US ECONOMY AS A TARGET

PART ONE: THE STRUCTURE OF THE U.S. ECONOMY

The U.S. economy is very vulnerable to nuclear attack because its industry is highly integrated and interdependent. Economic activity depends on a few essential industries which cannot be replaced. The energy sector is essential to sustaining economic activity: other particularly important industrial sectors include iron and steel works, nonferrous metals processing, electronic components, and petroleum products.

The various components of U.S. industry can function only when the rest of the economy is producing sufficient goods and services. Naturally, the needs of each sector are different; yet, two factors, the supply of raw materials and the services of the supporting infrastructure, are essential to production in any industry. The transportation and communication networks are crucial elements of this support.

In addition, many of the key industries are especially vulnerable, since they are frequently geographically concentrated, are inflexible in material requirements and depend critically on computer and transportation networks. This chapter will explore the characteristics of the economic structure that are responsible for its inherent vulnerability.

i) Economic Interdependence

A handful of industrial sectors are extremely critical. If these sectors produce less, the industries dependent on these products, suffering a shortfall in essential input, also produce less. The original shortfall is transmitted and amplified; thus, the final damage is far more severe than what may be initially apparent.

A 1977 Congressional report on Industrial Defense and Nuclear Attack by the Joint Committee on Defense Production discussed this amplifying effect [1]:

> Damage to one of the elements of the [economic] system will have consequences that ripple throughout the rest of this intricate structure with a severity that depends on the significance of the damaged portion and on the extent of the damage... An economy, therefore, can be crippled and perhaps extensively damaged for periods of time amounting to years.

Five of the most significant economic sectors identified in government studies are iron and steel foundries and forging, blast furnaces and basic steel products, machinery manufacturing, electronics manufacturing, and petroleum refining. Although these industries directly account for only a small fraction of national production, a drop in their output would be disproportionately disruptive to the rest of the economy. A study prepared for the Arms Control and Disarmament Agency (ACDA) in 1974 [2] assessed the effect of small reductions of only 10% in the productive capacity of these key industries. The final demand shortfall affecting the rest of the economy was calculated using input-output analysis (while such a technique may be unsatisfactory in representing the post-attack economy, it serves to illustrate how one industrial sector can influence others). The impact was multiplied as it was transmitted, since each of these sectors provides essential input for many other sectors. The iron and steel foundries and forging sector, essential for steel production, provides input for about 100 other sectors. Following the 10% drop in its capacity, production in dependent industries would drop even more, and the final demand shortfall would be over 40%, more than four times the initial shortfall. The disproportionality of the effect is a result of the singular importance of the steel industry, which provides supplies to so many other sectors: manufacturing automobiles, motors, engines, machines, turbines, measuring devices, tools, steel girders and communications equipment, to name a few. Similarly, the other four critical industries identified each supply over 100 others; if any of the four were to suffer a 10% reduction in output, related industries would experience a drop in output of 30 to 40%. These examples demonstrate the potential disruptiveness of even an extremely small Soviet attack, perhaps consisting of just a few weapons.

This multiplying damage might not be immediately apparent following an attack designed to bottleneck the economy. If a limited attack were to destroy several sectors but leave most industries with their stocks and inventories intact, the shortfall in a key sector's production would not instantaneously reduce production in all dependent sectors. Instead, there would be a time delay during which the inventories would continue to be used. Economic activity could possibly be sustained for some months immediately following such an attack. After some delay, however, inventory supplies would be depleted and the lack of output would begin to limit production in dependent industries, which would in turn influence others. The damage would propagate throughout the economy and output would fall. In a statement presented to a House of Representatives subcommittee in 1961, Sidney Winter, an analyst from the Rand Corporation, described the problem "of whether resuming production of the necessities of life can be restored before inventories are depleted" in dire terms [3]:

> Until this task of restoring production is accomplished, there is a continuing threat that the economic system will go into a spiral of cumulative disorganisation, a spiral which will come to an end only at a much lower level of economic life...

In order to sustain economic viability, some minimum level of production would have to be restored before inventories were significantly depleted. Otherwise, economic activity would necessarily be degraded for a prolonged period of time. Inadequate inventories would cause manufacturing to fall, which would reduce further the economy's ability to produce and maintain capital stock. This would further diminish manufacturing capacity. At the end of this collapse, survivors might well be occupied with agricultural subsistence instead of industrial production.

Building up even larger stockpiles of required materials or substitutes for the targeted products could reduce the immediate impact by allowing dependent industries to continue production for a limited time. Without a continuing supply of these requirements, however, stockpiling could only delay and never prevent economic collapse. Moreover, if stockpiles became large enough to be significant to post-war recovery, then they become targets themselves. The strategic petroleum reserve is a prime example of this.

As for finding substitutes for these key products, the most vital requirements for recovery cannot be readily replaced: how can new machine parts be manufactured without steel, in time to stave off collapse? How can the steel manufacturing industries be reconstructed without steel? And if there are substitutes for steel, how can the manufacturing capacity needed for conversion to these new materials be accomplished without steel?

Strategic targeting during World War II illustrated the importance of industries whose products are critical to other production, according to an Arms Control and Disarmament Agency Study study on war-supporting industry [4]:

> When contemplating limited nuclear strikes, it is possible to devise attacks which destroy a particular critical plant or industry, thus severely limiting, if not totally bottlenecking, the war production. The World War II example of the ballbearing plant has been duplicated in current strategic postures, bearing in mind present-day dependence on small precision instuments and other kinds of highly critical and highly concentrated technological industries.

The destruction of key energy facilities would be even more devastating than targeting the high-technology equivalent of the ballbearing plant [5]. After the Second World War, a German chief electrical engineering designer concluded [6]:

> The war would have finished two years sooner if you had concentrated on the bombing of our power plants earlier. The best plants to bomb would have been the steam plants. Our own air force made the same mistake in England. They did not go after English power plants and they did not persist when they accidentally damaged a plant. Your attacks on our power plants came too late. This job should have been done in 1942. Without our public utility power plants we could not have run our factories and produced war materials.

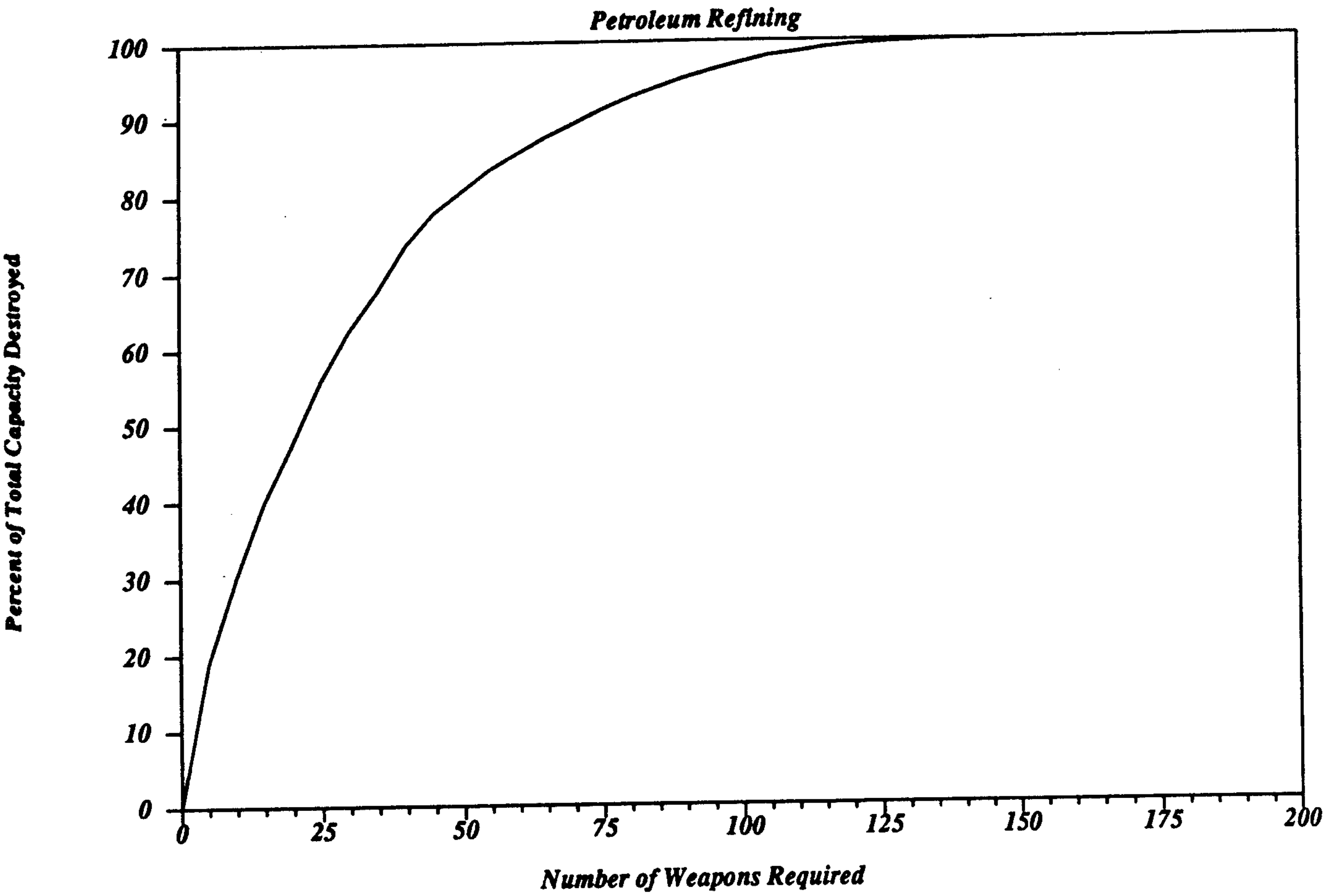
The availability of adequate energy supplies is perhaps the single most influential determinant of economic activity. Without the petroleum, coal, gas and electricity that fuel U.S. factories, production would grind to a halt. Substitutes for fossil fuels cannot run the nation's economic machine without extensive and <u>energy-intensive</u> conversion. Indeed, it is often true that a particular facility simply cannot switch fuels. In addition, energy facilities and stores can be easily destroyed by small weapons, since they are so flammable. With energy supplies constricted, the national economy would be crippled and could collapse. America's energy dependence and the particular importance of petroleum is confirmed by economic analysis and historical evidence, discussed in greater depth in the section entitled "The Role of Energy".

ii) Industrial Concentration

A 1978 Arms Control and Disarmament Agency [7] study found that half of all US industry is concentrated on two-thousandths of the total land area (7,400 square miles). These industrial installations lie within fewer than 800 circles of radius 1.7 miles or less. A very small weapon (about 100 kilotons) could devastate each target. The destruction of 50% of all of the nation's industrial installations would expend the equivalent of a few percent of the total Soviet megatonnage. Yet an even smaller attack, destroying less than half of all industry, could cause economic collapse (as we will attempt to show in later chapters), particularly if the targeting were directed at the essential industries.

Some industries are more vulnerable to nuclear attack than others because they are more geographically concentrated. For instance, petroluem refineries tend to be built in clusters. The location of petroleum extraction facilities is naturally constrained by the location of oil fields, which are often highly concentrated. Petroleum refining and petrochemical, plastics and fertilizer manufacturing facilities are often built near the extraction facilites to save transportation costs. These industries are almost as concentrated as petroleum extraction sites. If petroleum refineries were targeted, many other industries would suffer

Concentration of U.S. Industry



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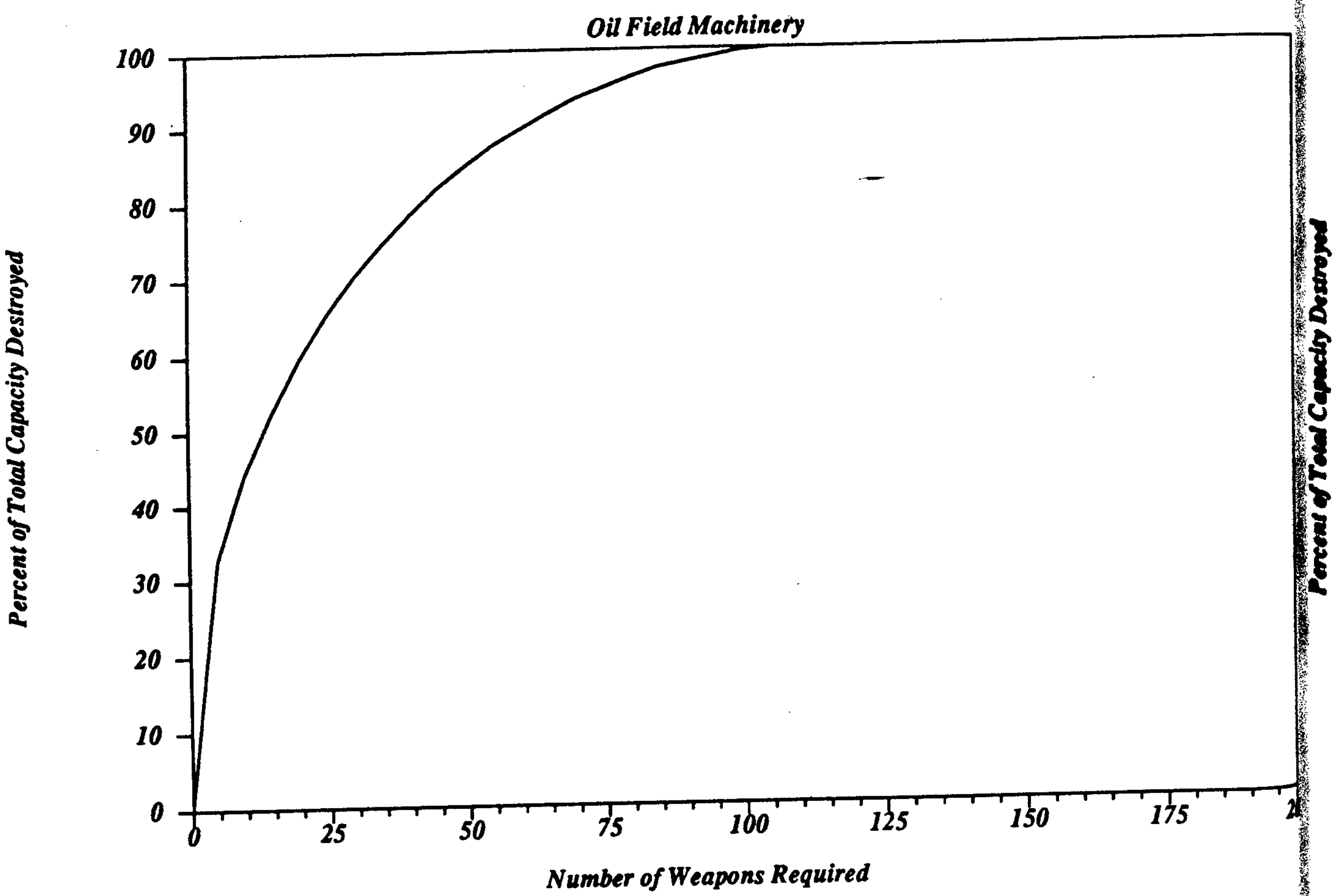

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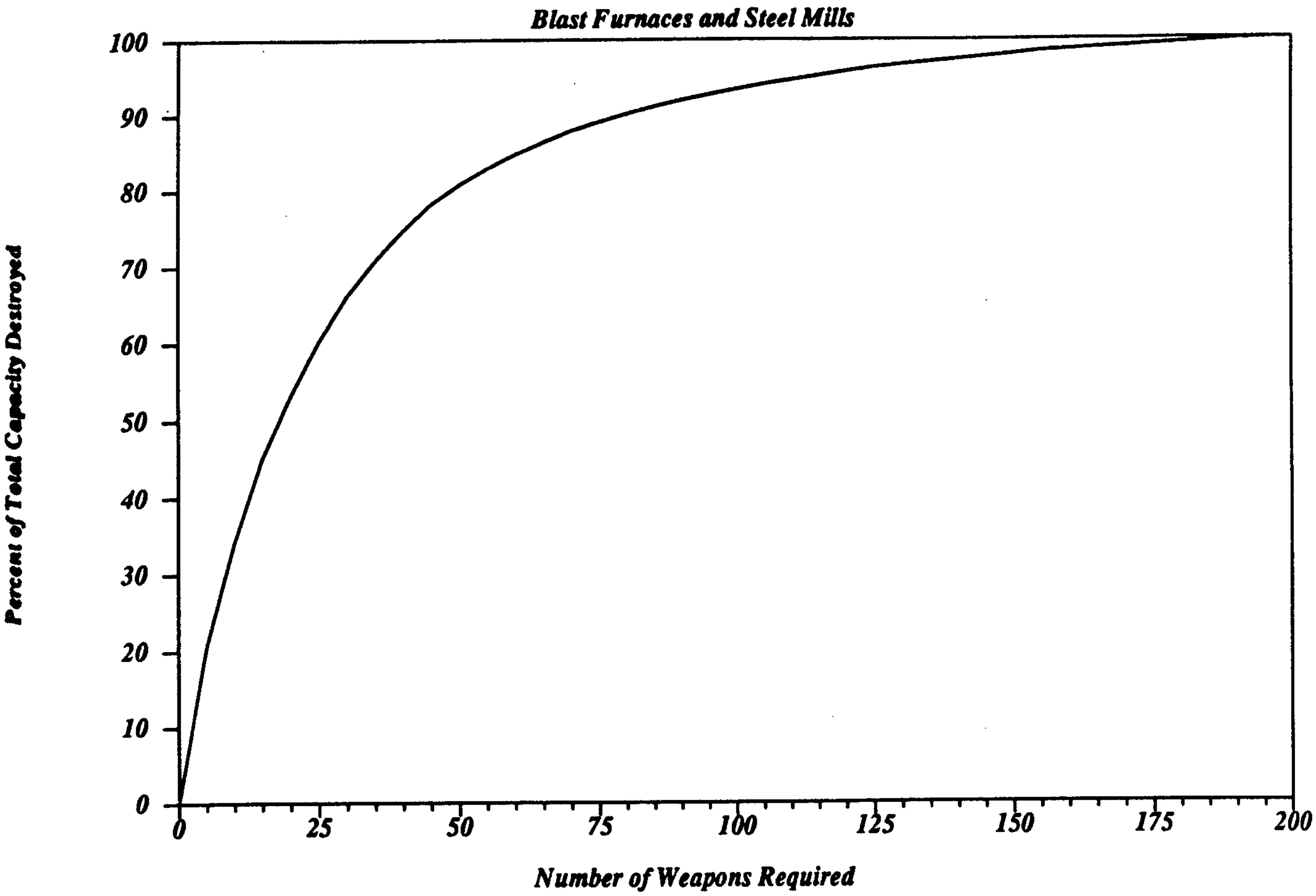

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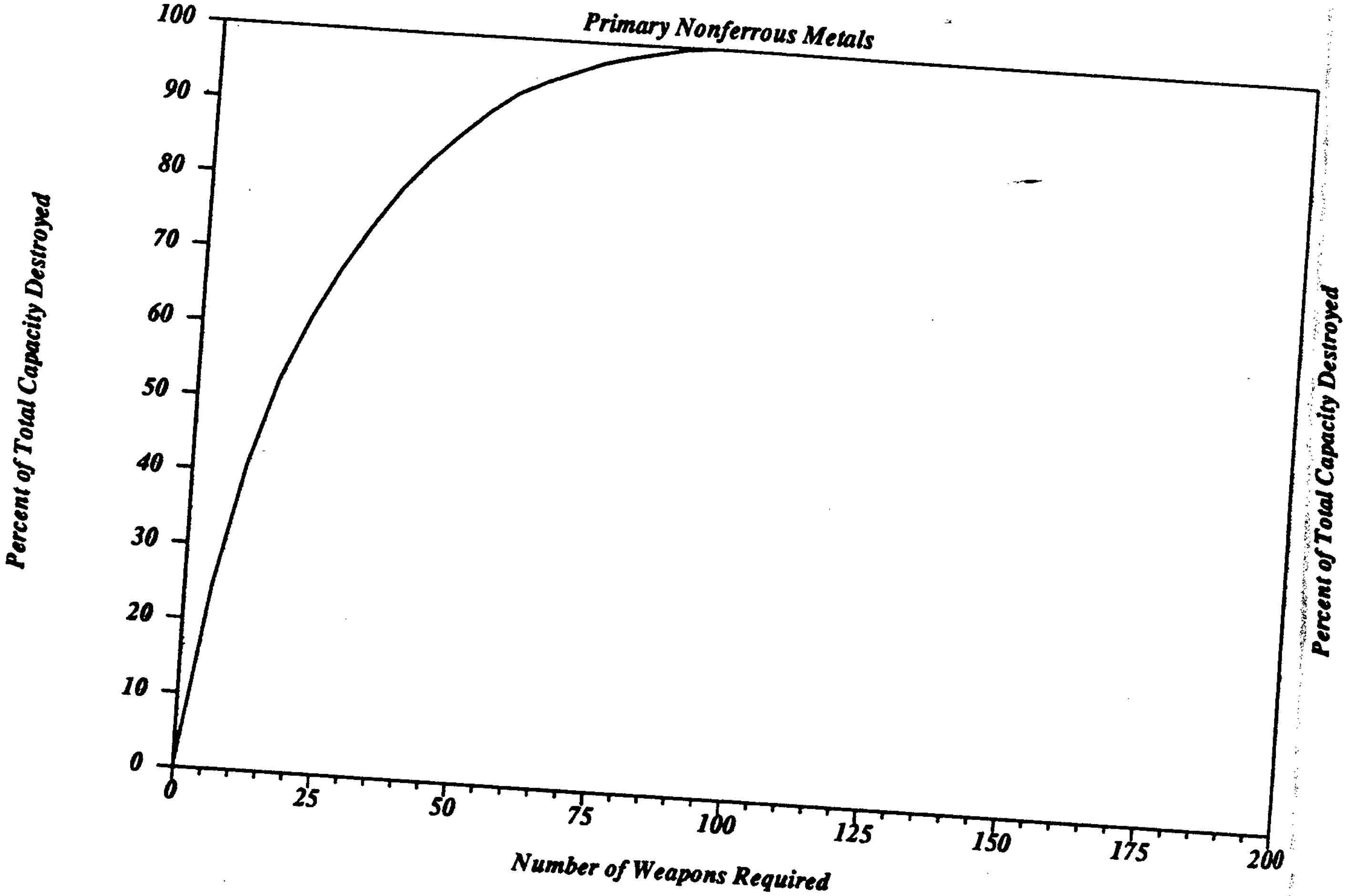

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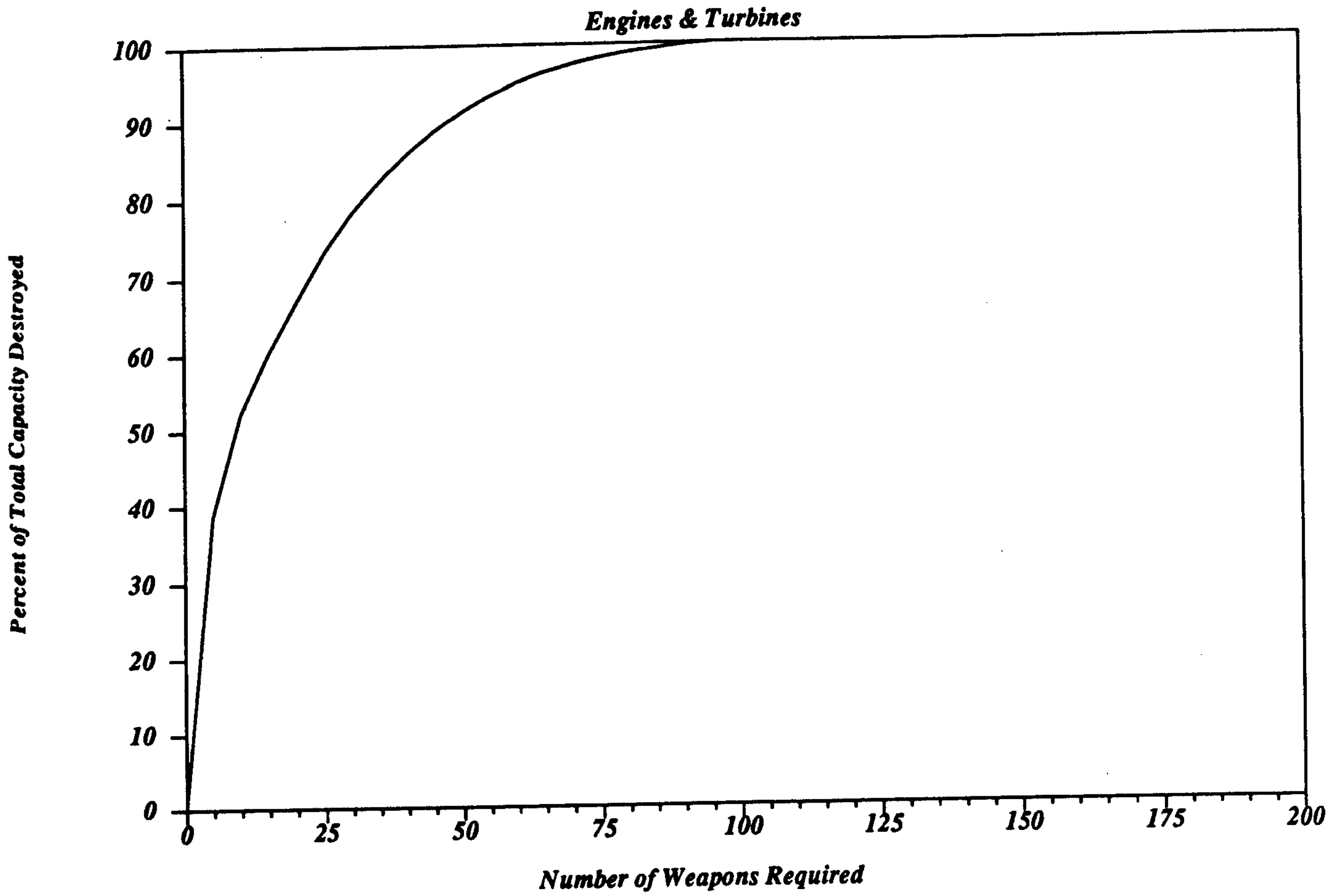

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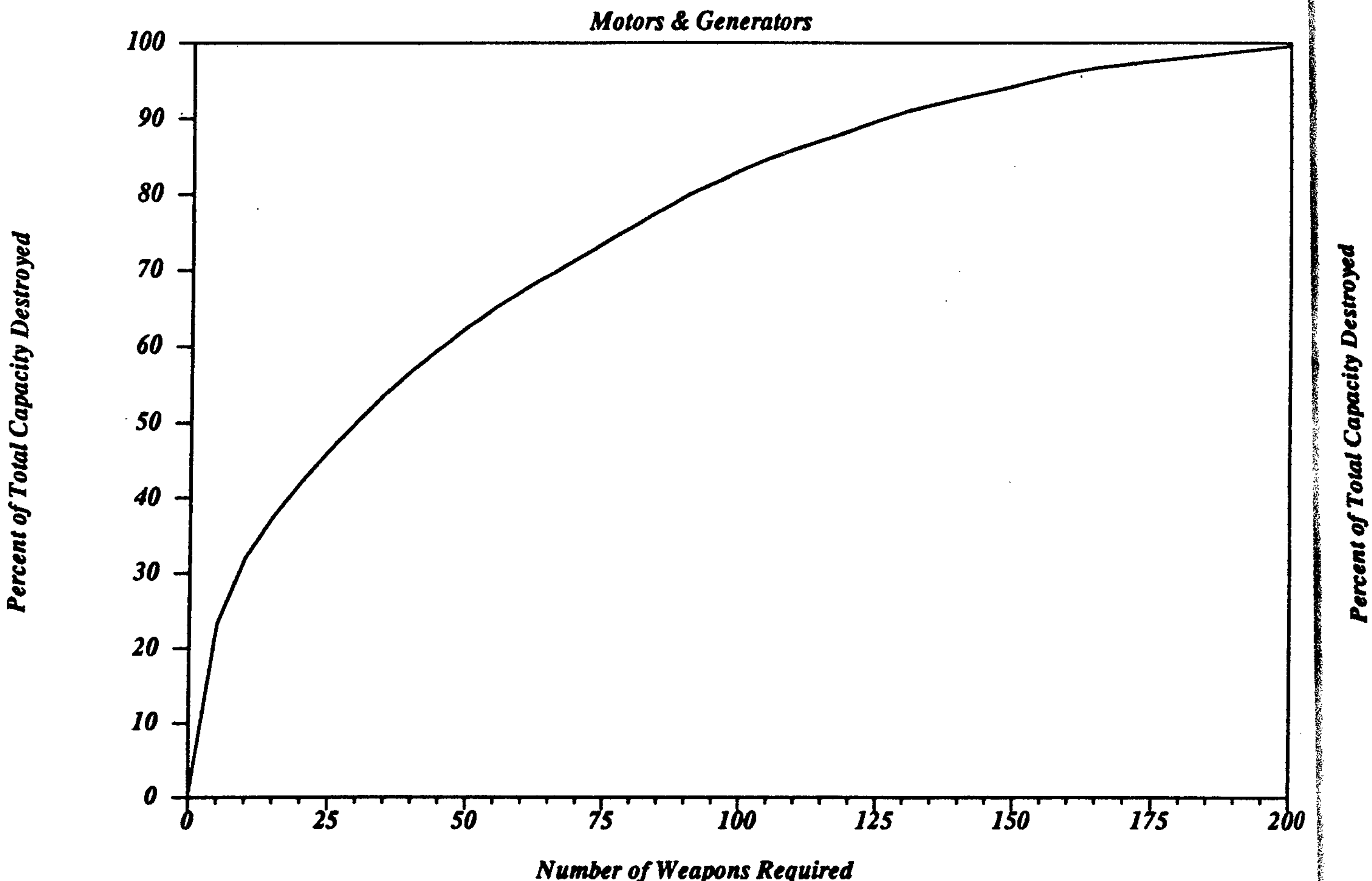

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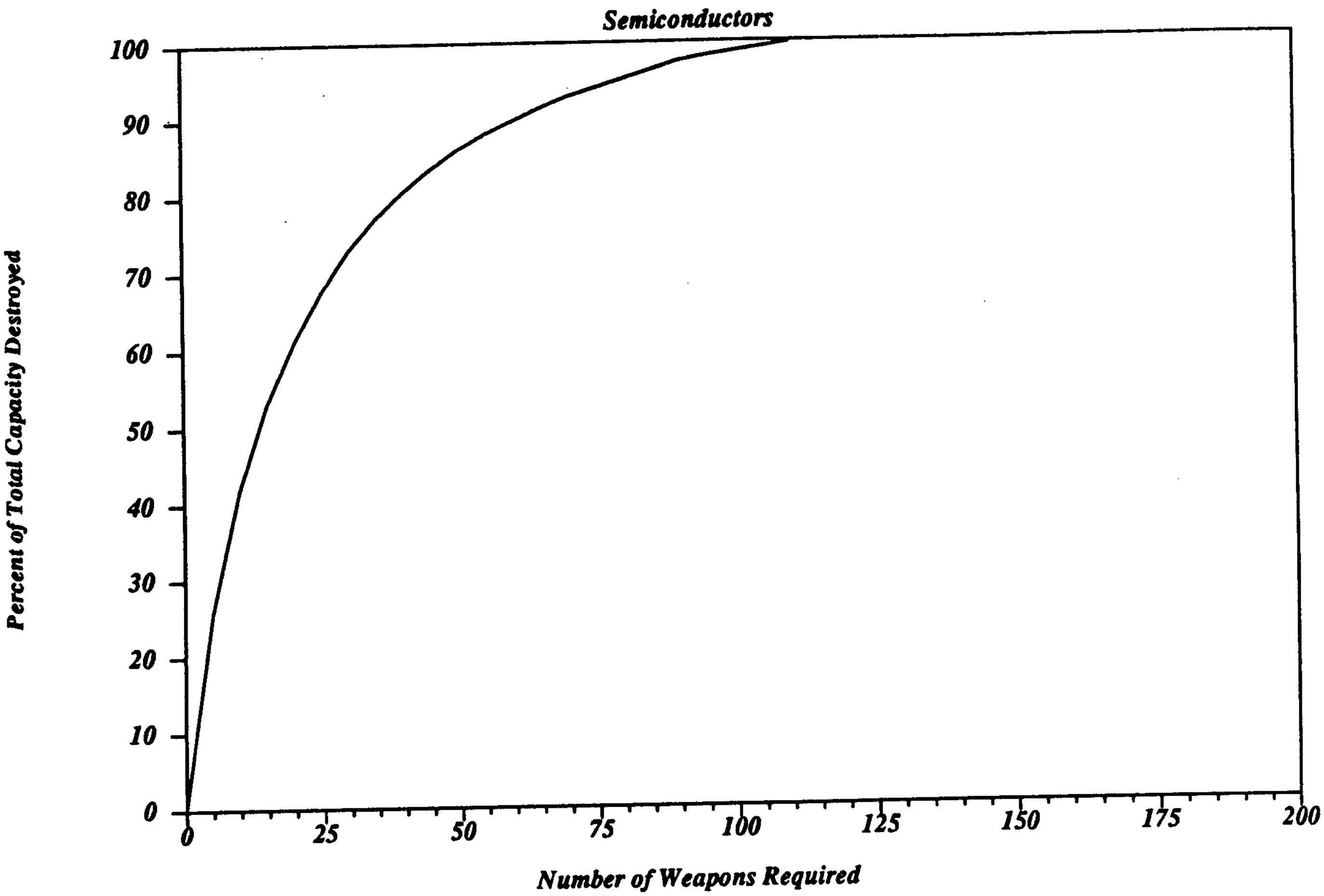

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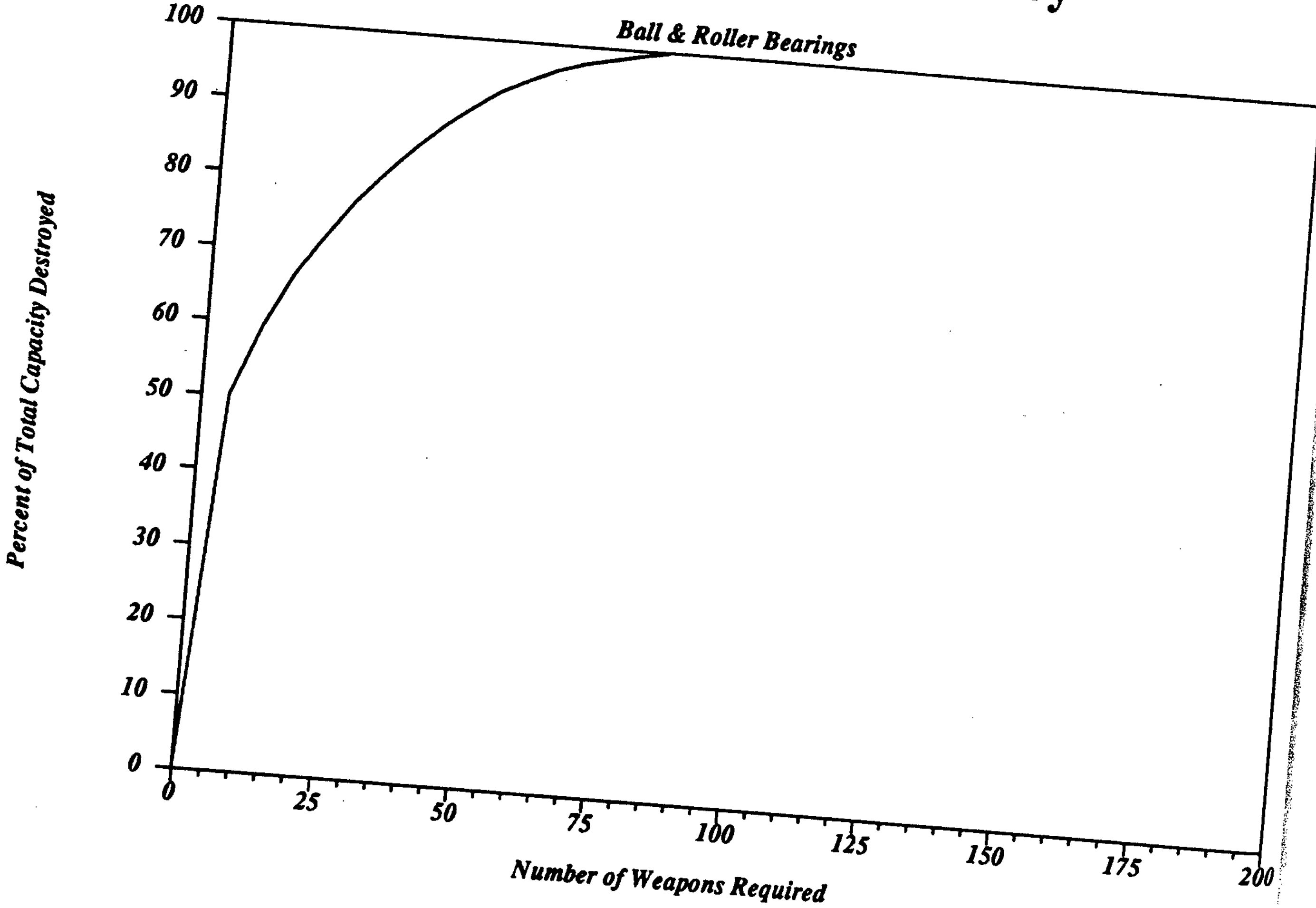

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heavy damage. This is referred to as collateral damage.

Following an attack on major U.S. cities, for instance, collateral damage would extend to the natural centers of the transportation network — rail and highway interchanges, ports, and airports. And construction of new ports would be more difficult after an attack once the best natural harbors were devastated.

The graphs on the next few pages demonstrate the concentration of some of the most essential industries. The percentage of the national production capacity is plotted against number of weapons required to destroy each amount for each of several industries, chosen because their capacity is concentrated and their products important. The weapons are all fairly small, 200 kilotons or 550 kilotons; the radii within which all plant and machinery is assumed to be destroyed are 2.6 and 3.6 miles respectively. The data base we used, a commercial survey of manufacturing
200 plants [8] gave detailed information on the type of industrial products and the factory location. Plants, or clusters of plants, were targeted by size. 100% of the petroleum refining industry is concentrated in 143 target areas and half in merely 21 small target areas. Virtually the entire capacity, 95%, would be destroyed by 90 weapons. The plants that comprise 80% of all oilfield machinery manufacturing are located within 42 target areas. The primary metals sector, which is vitally important, is extremely vulnerable because of its concentration: 80% of all blast furnaces are in fewer than 50 targets; other components of primary nonferrous metals manufacturing are similarly concentrated. About 80% of the primary nonferrous metals manufacturing is within 36 target areas.

Industries dependent on these primary products are also concentrated. For example, 80% of the engines and turbines industry is found within the lethal radius of 32 small weapons: 80% of all motors and generators manufacturing could be destroyed by 90 weapons, but destroying half of this sector would take only 30 weapons. For semiconductors, 80% is in 39 target areas and for ball and roller bearings, 29 targets include 80% of all capacity.

Within these target areas collateral damage would be significant for even very limited attacks. For example, a small 90-weapon "counter-petroleum" attack, equivalent to three-quarters of one percent of the Soviet arsenal (45 equivalent megatons or 33.5 absolute megatons), would destroy almost all the petroleum refining capacity. Collateral damage would be extensive: this small attack would also eliminate one-fifth of all ports and between 5% and 20% of many industries: primary and secondary steel and nonferrous metals; mining, construction, and oilfield machinery; ball and roller bearings; motors and generators; power transmission equipment; electron tubes; and semiconductors.

To illustrate the extent of this very limited attack, we list the major metropolitan areas targeted. The counter-petroleum attack would deliver between one and six weapons to each of these cities: Los Angeles, the San Francisco Bay area, Chicago, Houston, Denver, Baton Rouge, St Louis, Detroit, Memphis, Philadelphia, Tacoma and El Paso. Texas would be targeted with a total of nineteen nuclear weapons, Louisiana with nine, California with ten, and Illinois with six. Even though the actual targets are petroleum refineries, many of the weapons would explode on industrial sections of cities, sometimes several within the same urban area.

Selectively targeting several of the bottlenecking industries would require far fewer weapons than the numbers given for the 60/40 attack would indicate. Even in such a limited attack, collateral damage would be enormous. The majority of governmental offices, services, transportation, communications and energy facilities and industry, including the infrastructure needed to support it, is located in these same cities.

Most important of all, the bulk of the U.S. population (60%) lives in cities. Following an attack on multiple industrial targets, many of which lie in cities, most of the inhabitants of targeted cities would be killed. Many of the survivors would be injured, irradiated, and malnourished. Their bodies' immune systems would be impaired, their psychological health shattered. These tens of millions of injured survivors would require care and treatment far beyond the means of the surviving medical community [9]. Toxic chemical leaks and radioactive fallout would further threaten their survival. Faith in the official leadership and the traditional work ethic could be eroded to the point of anarchy. Yet, as we shall explain later, because these effects are so difficult to quantify, we have chosen the most favorable psychological responses to the disaster -- in our baseline analyses, the labor force suffers none of these negative effects and is instead co-operative and productive. But because the U.S. economy is so interdependent and geographically concentrated, even under these most favorable conditions it might take decades to recover from even a small strategic attack consisting of only 1% to 2% of the current Soviet arsenal.

iii) Support Infrastructure

Urban centers contain much of the network of services and utilities needed to maintain industrial activity, in addition to much of the industrial capacity. Destroying the industrial areas would destroy water and sewage pumping stations; electricity generation and transmission facilities; energy supplies and their distribution network; repair services, whose assets include human expertise, records and machinery; electronic information processing networks; and local and national transportation and communication systems. Within a targeted metropolitan area, a factory that did not suffer extensive physical damage could still be debilitated by the collapse of the economic infrastructure. On a national scale, the most important element of this infrastructure is the transportation network, which is treated more fully in the next section.

Just as the services and utilities essential to industrial production form a supporting infrastructure, so the services and utilities required for personal survival are needed to maintain the productivity of the labor force. This support system would also be damaged: hospitals, schools, churches, telephone exchanges, radio stations and shops destroyed; food, medical and energy supplies restricted. These are only some of the many factors that would make life miserable for the survivors, and severely diminish the productivity of the surviving labor force.

Educational and research institutions are another key element of the nation's economic activity. Following an attack that virtually eliminates petroleum refining as well as many other industries that utilise high levels of technology, the need for new manufacturing techniques and technological innovation would be intensified. Many engineering experts and technicians with a knowledge of plant operations would, however, be killed in the attack that destroys their industries. Records of plant design and specifications would be obliterated. Centers of learning and research, especially professional and graduate schools, are concentrated in urban areas. Contained within the 70 or so largest cities are 45% of the nation's institutions of higher learning, 55% of all undergraduate and graduate students and 70% of all professional students [10]. These universities attract research institutes, consulting firms and related industries, especially those in the valuable high-technology fields. The short-term consequences of their destruction would be the obstruction of recovery efforts to reconstruct and innovate. The long-term consequences to the U.S. economy and culture of the loss of many of the nation's finest universities and museums, research centers and sophisticated industries would be immeasurable.

iv) Importance of Transportation

Transportation is vitally important to the nationally aggregated, interdependent economy. Food, raw materials, petroleum supplies, and specialized goods (such as micro-electronic components), produced in a few, concentrated areas, require rapid transportation to all parts of the nation — thousands of miles daily. Such sectors are especially vulnerable to a nuclear attack that reduces the availability of transportation. Many of these sectors are also of paramount importance to economic recovery.

The U.S.'s economic activity is increasingly dependent on rapid transportation. Since inventory holding represents an avoidable expense and since national transportation is reliable, many firms now hold only a minimum inventory. Because the transportation system is efficient, fewer provisions are made for its failure, which increases the sensitivity of the national economy to shocks in transportation energy supplies. The oil crises of the 1970s demonstrated this dramatically.

Most threatening to the transportation network is an attack targeting its essential energy supplies. Petroleum is the predominant fuel; in its absence, automobiles, trucks, trains, airplanes, river and coastal barges and ships would almost immediately grind to a halt. Petroleum refineries -- considerably more concentrated and vulnerable to a nuclear attack than the nodes of the transportation network -- represent targets whose destruction would have catastrophic effects on that network. As we have noted, one vulnerability of the U.S. economy is its complete reliance on the transportation system; the vulnerability of this system, in turn, is its complete reliance on petroleum. The importance of petroleum will be discussed shortly.

v) Information Processing

Another product of the sophistication and specialization of the US economy is its dependence on information processing. The transfer of information is very important in the daily functioning of the national economy. Computers, electronic financial services and information processsing, telephones and electronic communications are required in all industrial sectors to transmit and record information about inventories, demand and production, to transfer funds and to monitor accounts. At best, chaos would follow a nuclear attack designed to disrupt these services; at worst, economic collapse would ensue. Moreover, as described in the previous chapter, it is possible that a single one-megaton weapon detonated 200 miles above the central U.S. could create an electromagnetic pulse that would severely disrupt all electronic and electrical systems.

PART TWO: THE ROLE OF ENERGY

More than one quarter of all energy consumed in the United States in 1986 was used to transport people and goods. Two thirds of all petroleum consumption was used in transportation. In 1986, almost all of the fuel used in transportation was derived from petroleum (nearly 98% of transportation was powered by petroleum; natural gas provided 2%; and electricity, less than 0.5%) [11].

Transportation

Since a few hundred small warheads would wipe out virtually all refineries, ports, strategic reserves and the pipeline system, and would immediately reduce petroleum avalilability to near zero, such a small attack could almost completely stop transportation. It could take many years to rebuild oil wells and refineries or develop alternative fuels. It could take just as long to reconstruct ports, pipelines, and pumping stations. Reconstruction itself would be severely impaired by the scarcity of petroleum and transportation after an attack. The extreme flammability of petroleum and natural gas only adds to the tremendous vulnerablility of these fuels to nuclear weapons.

Post-attack petroleum requirements can be reduced through eliminating leisure and nonessential uses. At present, air transportation, and local, suburban, and interurban highway passenger transportation account for under 30% of the transportation sector's energy usage. Motor freight transportation alone uses 40%; railroads and water transport, both of which are widely used to transport goods, total another 30%. These figures suggest that eliminating passenger transportation in an effort to cut petroleum consumption would probably not significantly cut fuel demand. Yet, this might be outweighed by increased transportation requirements during recovery efforts, when petroleum would be needed for the reconstruction of industry and the likely migration of much of the population away the devastated areas.

Furthermore, reducing minimum petroleum requirements would have little effect if virtually all production facilities were destroyed. The U.S. imports over a third of all the petroleum it consumes; however, more than 90% of all the petroleum used, all domestic petroleum plus three-quarters of all imports, requires refining in the United States. Foreign refining capacity may not be sufficient to replace U.S. refineries, but foreign imports would probably be cut off in the aftermath of a nuclear war. Even if the rest of the world were in a position to help the United States, ports and pipelines would be destroyed and irradiated in even a small attack. There would be no means to import petroleum without this distribution network. And once again, a major obstacle to repairing this network would be the scarcity of petroleum itself and the lack of transportation after an attack.

The bulk of the U.S. petroleum refining capability is in fewer than 100 cities and towns, which are located mostly in Texas, Louisiana, New Jersey and California. About half of the nation's refining capacity is in 48 of the largest cities. Only 90 weapons would destroy 95% of the national refining capacity. A total of 143 weapons on 258 refineries could devastate 100% of the US current refining capacity [12] to bring the nation's oil production to a standstill. Much of this capacity is concentrated near oil wells and the nodes of the pipeline system, in the same areas where strategic petroleum reserves are maintained. Natural gas extraction and processing is also concentrated in these areas, in Texas and Louisiana. In the other industrial regions of New Jersey and Pennsylvania, much of the essential petrochemical industry is located close to refineries. While petroleum refining would be halted, so too would crude extraction, natural gas production, and petrochemical maunfacturing. The oil and gas pipeline would probably be damaged beyond use and strategic reserves left burning until depleted.

Directly following a carefully planned attack on energy, the U.S. would have lost virtually all of its ability to refine or import petroleum. An immediate danger following a sudden, drastic reduction in petroleum availability is that this shortfall will cut off access to existing fuel stores in oil fields. The nation could be locked in the desperate position of having adequate fuel supplies but no way of extracting and distributing them. In this case, the fuel would be useless. Fuel is needed to extract fuel: thus there exists some minimum energy requirement, an energy threshold. Once this threshold has been crossed, economic activity would probably dwindle to a lower level, at which point labor replaces mechanization, before recovery is possible. The economy could fall into a "spiral of cumulative disorganization" [13]; energy inadequacy would cause this collapse. The spiraling collapse of the national economy would be the result of a powerful vicious circle that is inherent in our nationally integrated economic structure. A minimum amount of the appropriate fuel is required to make other fuel reserves available, so that with less than enough fuel available, less and less additional fuel is available.

Despite the seeming improbability of energy availability sinking this low, the Government of India found itself nearing such a position in late 1979. The Secretary for Industry, V. Krishnamurthy, described the situation in the New York Times [14]:

> At present the No. 1 problem is power. A power cut means lesser output in coal mines, and this in turn means a fall in thermal power. This has been going for many months. It is a vicious circle.

The crucial importance of immediately-available substitutes for petroleum in transportation is evident. In the next section, we discuss possible transportation fuels.

Replacing Petroleum

As we have seen, immediately following an attack on energy, refined petroleum would be scarce. Unfortunately, the extent to which gasoline use can be cut back without industry and consumers suffering severe consequences is limited.

According to former Department of Energy assistant secretary Alvin Alm [15], a reduction in petroleum imports of 6 or 7 million barrels per day (a drop of about 40% in imports) would render the nation "virtually immobile" and plunge the economy into a slide worse than the Great Depression. Existing government contingency plans for fuel rationing, Alm adds, "would lead to chaos.... Any federal attempt at rationing, no matter how well intentioned, would increase confusion and heighten public cynicism." Futhermore, even peacetime crisis planning for alternative fuel development can be difficult: "all these decidedly optimistic scenarios for increasing energy output assume an extraordinary degree of governmental and financial support" [16]. It is quite likely that such support would be lacking in the aftermath of a nuclear war.

Domestic US consumption of petroleum now stands at 16 million barrels per day. Some of petroleum's industrial uses can be substituted by other fuels. The easiest substitution would involve "switching" to other fuels in facilities that can be quickly adapted for this purpose. According to a report by the National Petroleum Council [17], electric utilities have an oil-to-gas conversion potential that would eliminate demand for about 1.5% of total petroleum usage (240 MB/D, or 240 thousand barrels per day). Under the best peacetime conditions, it would take six weeks to convert electric utilities. In industrial boilers, coal can replace the equivalent of 0.3% of the total oil usage, and 1.4% of gas. Other industrial uses of oil, a total of 0.5%, can be replaced by an equivalent amount of gas and electricity. Switches within the industrial sector could be realized in six months, in the best emergency situation (a relatively small interruption of foreign oil supplies, with a great deal of governmental efficiency). To reduce total oil demand another 0.4%, electricity presently supplied by oil-fired plants could be replaced by "wheeling in" nuclear- and coal-generated electricity from other plants, whose generation would have to be stepped up. All these measures together would allow a reduction of 4% in petroleum supplies. In the face of near-complete reductions of petroleum, such measures would not accomplish much.

The extraction of coal, a substitute for petroleum in heating, electric utilities, and industry, is now dependent on petroleum. Efficient strip mining requires huge gasoline-fueled power shovels and high-speed unit trains, which shuttle between coal field and market center and are essential for efficient transportation of coal. Alternative means of extracting and transporting coal would be implemented, but at a loss in efficiency and productivity. Since the most accessible ores have already been mined, mining is increasingly capital-intensive and fuel-expensive, although this is offset somewhat by improvements in efficiency through technological development. Typically, of the fuel used in coal mining, about half is petroleum products. Diesel fuel and gasoline account for two-thirds of the energy used in surface mines, and a fifth of that used in underground mines. Including the transportation of coal and machinery and the commuting of workers, petroleum dependancy is actually very much greater.

The energy requirements for oil and gas extraction are even more demanding than those of coal extraction. Nearly three-quarters of all energy used in the entire mining sector is consumed in oil and gas extraction. This includes neither the fuel lost in extraction nor the important indirect costs of drilling and exploration. The energy cost of natural gas refinement is 30% to 50% of its own refinery fuel. In refining alone, petroleum energy requirements equal 1/8th of its energy equivalent.

This energy expenditure, unavoidable and not insignificant, does not include any of the transportation requirements; these also depend heavily on petroleum. Both natural gas and petroleum pipelines are used extensively for distribution. Within these systems there exists about a five weeks' supply [18], much of which would be destroyed in the attack. Any remaining would prove extremely difficult to retrieve and distribute.

Perhaps more significantly, facilities that produce these petroleum substitutes in usable form — gas, coal and electricity (including that from nuclear reactors), as well as other fuels -- would also have been destroyed or damaged, severely reducing their availability. The attack would also directly destroy much of the means for the nationwide transportation of these energy supplies. Pipelines, transmission lines, control equipment for electricity networks, and the key nodes of the transportation network are targets in this attack, either intentionally or because they happen to be located near important targets. And without adequate supplies of these forms of energy, most other substitutes for petroleum could not be mined and transported.

Attempts to substitute other forms of energy for petroleum thus seem unlikely to significantly improve the severe energy shortage after an attack. In addition, the lack of transportation would prove a severe hindrance to any attempts to deal with this post-attack energy shortage. Petroleum, crucial to transportation, would, as we have seen, be almost completely unavailable after an attack. Neither natural gas nor electricity, which currently provide a small fraction of the energy used to transport materials and people, would be available after a nuclear attack on energy facilities; even if they were, they would be relatively useless. For example, a small amount of electricity (only 0.2% total transportation energy use) powers railway trains, mostly urban transit systems. These track-bound shorthaul systems cannot provide the necessary interstate goods conveyance needed to sustain the post-attack economy; in any case, if major urban centers are targeted, they would be devastated.

The pipeline system would also fail following a strategic attack. Natural gas powers its own pipeline system (which is included in the transportation sector as the conveyance of fuels via pipeline). Natural gas, crude petroleum, petroleum products, coal slurry and water are all distributed by pipeline. Vast stretches of the pipelines, including the key nodes, would be destroyed in the attack, and damage to even a part of the system can make the entire network useless. Electricity is also used in the pipeline system, driving pumps for all these fuels. Yet, as we have seen, electricity may well be unavailable directly after an attack.

Thus it is likely that the pipeline system would be inoperable after an attack. If pipelines cannot be used to tranport much energy after attack, then trains or trucks will have to do it. Yet, existing fuels for those vehicles will be unavailable after an attack. And the extent to which gasoline can be substituted for by other fuels is limited. Coal, the traditional substitute for petroleum in industrial boilers and electricity generation, currently has no direct use in transportation. Rebuilding coal-powered railway locomotives would be a lengthy process, necessitating much energy, steel, manpower and technical expertise that could well have been lost. The network of railway lines would be destroyed in many places and may not in any case be appropriately distributed to serve the relocated survivors. As we have seen, natural gas, and nuclear power are equally unfeasible as transportation fuels, especially in the months following the attack.

Alternative energy sources include synthetic fuels. After the capital-intensive process of synthesis, however, these fuels still require refining, like crude oil. Natural gas liquids ("wet" gas removed from gas deposits) recently accounted for 1/10th of all domestic oil output. Coal-based synoil and syngas production is more capital-intensive than petroleum refining, and large-scale plants for synthesizing liquid fuels from coal do not exist. Synoil, which is formed from a mixture of hydrogen and coal, must also be refined in the same manner as crude oil. Oil-shale and tar-sands present two potential sources of oil but are also as yet economically unviable, with no commercial plants operating. Since they all require refining in addition to synthesis, any of these alternative fuels is even less useful than crude petroleum.

The use of ethanol as a motor fuel is restricted by the lead time and land-intensity of its production process: crops used to produce the alcohol must be cultivated, equipment needed to synthesize ethanol manufactured, and gasoline-consuming engines converted. In addition, agricultural land not contaminated by fallout would probably be needed for food production and the availability of land for energy crops might be limited. Conceivably, some of the contaminated land could be used to produce ethanol; but without gasoline, petrochemical fertilizers and machinery parts, much labor would be needed. Although it might seem that the US would have a great deal of excess crop land after a nuclear attack, the nation's current ability to produce vast amounts of food is dependent on a very high level of technology. Moreover, by increasing the size of their attack and ground bursting a few dozen weapons in the Midwest, the Soviets could irradiate tens of thousands square miles of cropland, rendering them uninhabitable in the short term and severely complicating any US efforts to grow food or alcohol crops.

Thus, none of the components of the transportation sector would be operating following an attack that eliminates petroleum refineries and nodes of the electricity grid and pipeline network. The development of substitutes for refined petroleum would require substantial time, resources, manpower and technological expertise.

Rebuilding Energy Facilities

The facilities that provide energy are also the ones that require the most energy to construct. Of all types of construction (including industrial and commercial construction), new petroleum pipelines are the most energy-expensive, followed by new gas utility facilities, new highways, the maintainance of petroleum pipelines, new oil and gas wells, and the maintenance of oil and gas wells [19]. The first items on this list are almost exclusively concerned with producing and distributing energy. Maintaining energy facilities in working order uses much more energy than constructing new telephone and telegraph facilities, halfway down the list, and housing and hospital construction, about two thirds of the way down the list.

Besides requiring the most energy, energy facilities also require the most money to construct: technical expertise and specialised, delicate equipment are expensive. More than one hundred billion dollars' worth of U.S. power stations represent the most valuable fixed industrial asset in the country. Cryogenic tankers for transporting LNG (Liqufied Natural Gas, a crude oil substitute used in the US and Canada) are the costliest non-military, sea-going vessels, worth $100 million each. LNG liquefaction and gasification plants cost a billion dollars each, and nuclear power plants are even more expensive, representing the most expensive plants in US industry. Both LNG and nuclear power plants are extremely vulnerable. Even without a direct hit, a shock wave can rupture containment vessels and could cause massive LNG explosions or a nuclear plant core meltdown spreading high levels of radiation (apart from weapon fallout) that would make the vicinity uninhabitable for many years [20].

The capital-intensive, energy-expensive construction of energy facilities is also subject to another constraint: the long lead times involved in building new power plants, nuclear reactors, and petroleum refineries. Typically this time is ten years. Average construction lead times for merely repairing substantial damage are long -- five or six years for a coal-fueled steam power plant, eight for a nuclear power plant. Often, construction can be stalled for many months or longer by requirements for exotic materials and fabrication techniques. Following a nuclear attack, these essential factors would be unavailable. Indeed, most of the inputs required to rebuild refineries -- such as steel and other metals -- are explicitly targeted in the larger attacks because they are the products of bottleneck industries.

Summary

Energy would be very scarce for a long time after a carefully planned attack. The direct targeting of petroleum together with an attack on natural gas and electricity would make these fuels almost completely unavailable, which would in turn make extraction of other fuels difficult, at best. In addition, transportation, including transportation of fuels, would be brought to a standstill. The crucial post-attack economic goal -- producing and transporting enough energy to keep energy availability from spiraling rapidly to zero -- might well be unattainable after a properly planned attack, a point we will examine in detail in later chapters.

It bears repeating that we are not suggesting that the Soviets are actually planning "tiny" attacks like the counter-energy attack, but rather we are trying to show just how vulnerable the U.S. economy is to nuclear attack [21].

CHAPTER THREE

METHODOLOGY

General Problems with Computer Models

Computer modeling of social and economic systems is about three decades old, but it is still far from perfect [1] and remains a source of controversy and front page news [2]. There is nothing new about modeling reality so that we can understand it and predict its future state. We make use of mental models of the world around us all the time. Mental models usually involve making assumptions about the system to be modeled that allow only a fraction of the relevant information to be taken into account. The model may prove useless because 1) the modeler may have had a parochial perspective 2) she may have had incomplete, dated, or biased information, or 3) she may have been unable to track rationally all of the assumptions — explicit or hidden — she has made together with all of the possible alternatives.

Computer models, if properly contructed, are an improvement over mental models because

i. They are explict, and their assumptions are documented.

ii. They compute the logical consequences to the assumptions without error or bias.

iii. They are more nearly comprehensive, interrelating many more factors simultaneously than the human mind.

But computer models have shortcomings. They are, for instance, unable to deal with relationships and factors that are difficult to quantify, or which are outside of historical experience and therefore difficult for the modeler to replicate in the computer model. All models are simplifications of reality; their utility for assisting decision-makers improves as irrelevant factors are left out of them and all assumptions included or excluded in the model are clearly stated and their implications fully explained.

Simulation models, such as the FEMA model we used to analyze the effects of a nuclear attack on the U.S. economy, are meant to mimic the real system -- in this case the U.S. economy -- and help us ask "What if?" questions that cannot be asked using the real system. Simulation models have two components -- a representation of the physical world relevant to the system under study, and a description of the relevant actors in the system (in this case the economic behavior of the U.S. people after a nuclear attack) and how and why they make the decisions they make. Therefore, a simulation model does not tell us what to do, but rather what will happen in a given situation.

A simulation model is only as good as the assumptions it contains and the accuracy and adequacy of the representation of the physical system it describes. Good simulation models are flexible, incorporating feedback, non-linear effects, and dynamic behavior, and they do not assume that the systems they represent necessarily be in equiblibrium or necessarily behave in the future exactly as they have in the past. To be useful, a simulation model must portray the changing of decision-making patterns in response to the changing conditions. We cannot assume, for example, that the day after a nuclear attack people will behave in a "business-as-usual" pattern; if the model is to be useful, this changed pattern must be reflected in the model. To do this, the modeler has to draw on psychological, anthropological, ethnographic, and historical data, as well as direct observation and interviews of the relevant decision-makers. All this is introduced into the model in the form of variables which can be quite intangible and difficult to quantify ("soft" variables) such as optimism, expectations, fears, and desires (as opposed to "hard" variables like GNP). Moreover, these variables are imposed on the model from the outside (so-called "exogenous" variables, as opposed to "endogenous" variables, again, such as GNP, which the model calculates itself). Nevertheless, although these variables are both soft and exogenous, they cannot be neglected. In the FEMA model they are introduced parametrically, under the collective name of "psychological effects." As will be discussed in detail further on, their presence can have devastating consequences, and to ignore them would certainly be wrong. We chose instead not to use them in any of our baseline cases to avoid overly pessimistic results, and then examined their effects on those baseline cases.

A Flawed Computer Model

Some of the potential modeling pitfalls can be seen in a model developed by the Stanford Research Institute (SRI) for the U.S. Army and discussed in a 1973 report entitled "Analysis of the U.S. and USSR Potential for Economic Recovery Following a Nuclear Attack" [3]. Perhaps the most serious problem with the SRI study was its aim [4]: "The objective of this study has been to develop and exhibit preliminary but plausible postattack recovery schedules for various levels of attack objectives."

That is, the SRI model was a so-called "growth" model that was designed to recover, and indeed SRI calls its static 15-sector aggregated input-output model the "economic recovery model." Some of their results are presented in Figure 3.1, which shows the behavior of GNP through time. GNP follows a remarkably similar path following all of these attacks -- even though the size of the attack ranges from 250 to 1250 megatons. Why is this so? As the report states (emphasis added) [5]: "The steady recovery after the first two years shown on all schedules is built into the models but is considered to be realistic in view of firm government controls suppressing the political or economic perturbations which normally occur in peacetime." There are several problems with that assumption:

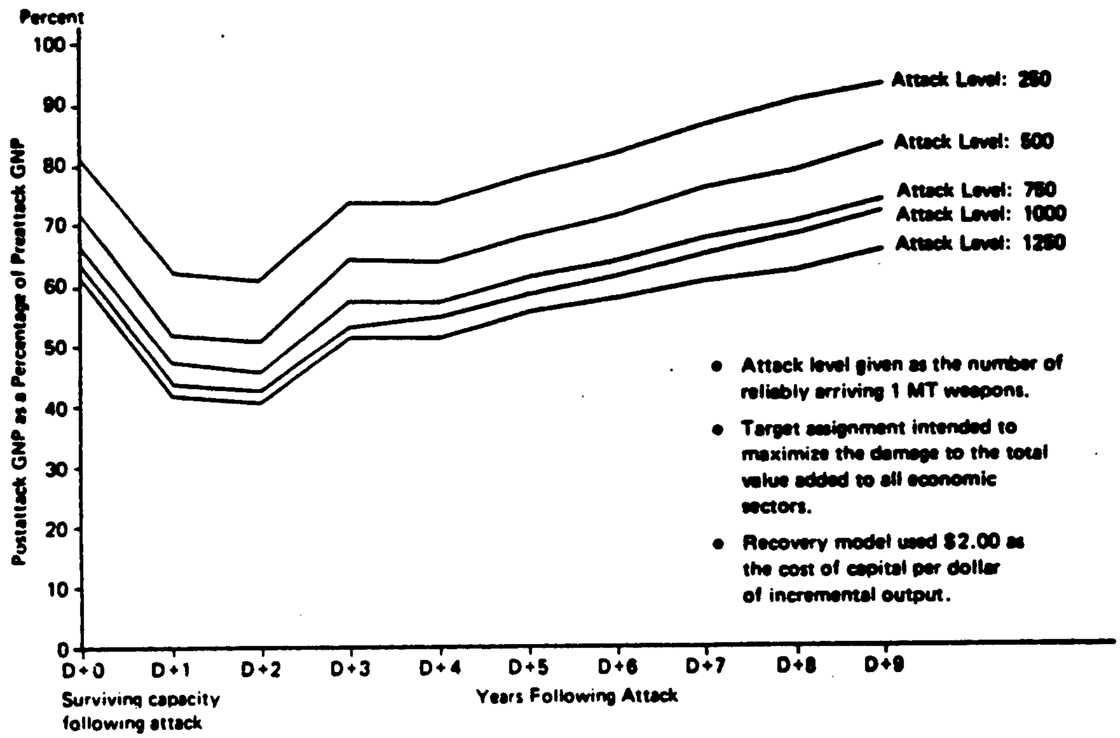
i. Why would firm government control avoid post-attack economic perturbations when many experts feel that government control is a large part of peacetime economic perturbations?

ii. Would centralized coordinated government controls be possible after as many as 1250 megatons were dropped on the U.S?

iii. Most important, since economic collapse -- or at least economic stagnation -- following a large nuclear attack is at least a possiblity, then the SRI model, which was explicitly designed not to exhibit either of those behaviors, is inherently biased and unrealistic, and therefore of very questionable use to any prudent U.S. planner.

Such is the pitfall of building the desired answer into your model. The authors of the SRI report have, at least, stated their assumptions, and they concede that the models they use provide "upper limits on potential recovery. Projected recovery rates should prove overly optimistic when

Postattack Recovery Measured by GNP – U.S.[a]



a. Fifteen Sector Model.

Source: F.W. Dresch, and S. Baum, *Analysis of the U.S. and USSR Potential for Economic Recovery Following a Nuclear Attack*, Stanford Research Institute, Strategic Studies Center, (Menlo Park, California, January 1973). p. II-8.

Figure 3.1

compared with rates realilzed in a real case." [6] Yet, even in the 250-megaton attack of the SRI report, the U.S. economy has not reached its pre-attack level 9 years after the attack (and the GNP is far less than it would have been at that time if there had been no attack).

Other pitfalls are demonstrated by the SRI model's simulated 250 megaton attack on petroleum refining. The first year after attack, the GNP was 23.7% of the pre-attack level, the second year it was down to 21.8%, but the third year it was 61.4%! (the fourth year it was 70.6% and the fifth year it was 93.7%). Why does the GNP triple between the second and third year? "The two year cycle is largely a consequence of the two-year lag assumed to be required for capital replacement." [7] Because the nature of post-attack capital investment and replacement can only be guessed at in the SRI model, the capital replacement time lag variable is an exogenous one in the sense that the modeler has to arbitrarily determine its value and impose it on the model. On the other hand, the idea that most of the petroleum refineries are going to reconstructed all at once, causing tremendous GNP growth in one year, is wildly unrealistic. This is especially true since energy-intensive projects such as petroleum refinery construction will have to be carried out during a period of serious petroleum shortages. As the report itself states, "the recovery models ignore many institutional factors that could make it impossible to achieve the recovery rates projected" [8] Moreover, "the recovery model ... is not capable of treating effects of transportation bottlenecks" [9], which we have argued will be crucial during petroleum shortages.

If, as SRI says, their results are "upper limits on potential recovery," then it may be reasonable to expect that an actual 250 megaton attack on petroleum refineries could collapse the economy. Given the devastating nature of the 250 megaton attack on refineries, it might be expected that SRI would examine larger attacks on refineries or the entire energy sector, up to 1250 megatons, as they do with their general attacks on the whole U.S. economy. If they did make such an examination, they do not reveal the results in this report (although they do indicate in an appendix that while 250 weapons would reduce refining to 10% of its pre-attack level, 500 weapons would reduce it to only 1% of its pre-attack level). Finally, since a much smaller weapon than one megaton is sufficient to destroy a refinery, it may be that a much smaller attack than 250 megatons could have the same devastating effect [10].

The SRI economic recovery model shows the dangers of 1) designing a model with a certain result in mind, 2) using static, linear, growth models to examine the U.S. economy after a nuclear attack, 3) using biased and unrealistic assumptions, and 4) failure to test input parameters over a wide range of values.

A More Realistic Approach

We have studied a computer model of the U.S. economy that was designed to minimize or avoid all of these dangers. Produced under contract to the Federal Emergency Management Agency, FEMA, this simulation model was created specifically for the purpose of analyzing the post-attack economy and predicting the effects of different types of perturbing attacks against the United States. We refer to it as the "FEMA model." The technique it employs, called System Dynamics, is interactive, dynamic, and flexible. These qualities are essential to accurately model the response of a complex system to various perturbations without historical precedence that throw the system severely out of equilibrium. A computer model designed to simulate a system as complex as the U.S. economy must incorporate thousands of simultaneously interacting variables, each one representing some aspect of the flow of materials and information among the various producers and consumers that make up the national economy. The problem of simulating the economy is particularly difficult in this case, since non-equilibrium and atypical conditions would arise in the aftermath of a nuclear attack. These circumstances argue against using simulation techniques such as econometrics and input-output analysis (such as the SRI economic recovery model), which tend to assume the economy is in equilibrium and use historical experience as necessary inputs.

Aware of the limitations of computer simulation models, we have subjected the FEMA model to extensive testing that we describe below. We find that the answers the model gives to several "What if?" questions are often sensitively dependent on the value of some exogeneous (or extrinsic) variable. By using the entire range of such variables in our sensitivity tests, we have attempted to bring forth the full range of possible answers the model provides for each question. Therefore, we do not regard any one scenario or set of parameters as the <u>right</u> answer. The model is not an oracle from which we can expect the right answer, but rather it is a tool with which we can ask complex questions about a very complex system (the U.S. economy) variably perturbed by sizable, near-instantaneous events (nuclear attacks).

In the remainder of this chapter, we present the important characteristics, and shortcomings, of the System Dynamics approach and discuss why it is appropriate for modeling the post-attack economy. Following a description of the model, its structure, and the way it can represent a nuclear attack is an explanation of how we interpret the results it produces.

THE TECHNIQUE: SYSTEM DYNAMICS

System Dynamics is a modeling discipline supported by computer software designed to manage complex, interdependent variables. This technique leads to an explicit representation of the dynamics of change, since each variable is updated whenever any of its determinants change. The behavior of a system of variables as depicted by a System Dynamics model depends on the interaction among all the elements of the system, in our case the variables that comprise economic sectors; as noted earlier, it is this interaction that constitutes economic activity. These interactions, in turn, are influenced by external conditions (such as the attack itself), and by factors such as the availability of imports, and the policy response to the disaster (such as investment policies favoring reconstruction of transportation and energy facilities). The nature of each interaction changes as conditions change, and a change in one variable (number of people) could change a second variable (amount of health care available per capita) that would in turn change the first variable (number of people) again. This is the mechanism, known as feedback, that is responsible for the dynamic behavior of System Dynamics models [11].

Especially relevant to the problem of representing the post-attack economy is the flexibility of System Dynamics. Because this technique can represent non-linearities, variables can remain realistic over a large range of possible values. Another advantage of this technique is that inherent in the model structure are the critical feedbacks that actually exist in the economic structure that it represents. In testing the model, the user gains a deeper understanding of the structural constraints of the system and learns about features that are responsible for its behavior. For example, exploring the consequences of very low availabilty of fuels in the FEMA model leads to an understanding of the minimum "energy threshold," which results because fuel is required to extract further sources of energy. Because of its realistic depiction of causal relationships, the System Dynamics model does not require simplifying assumptions such as linearity of effects and equilibrium of markets. In many other economic modeling techniques, demand and supply are calculated according to the principle that the two must balance. Assumed equilibrium is not a constraint in System Dynamics models, since excesses of demand and supply are permitted, and are manifested as pressure to increase or decrease production respectively. Relationships represented in the model correspond to both real and perceived flows of resources, capital and information, and include such realistic features as saturations, limiting factors, and multiplicative effects. The time evolution of any variable can be plotted, and it is easy to reformulate any relationship to test the impact of different assumptions and policies.

The techniques of System Dynamics integrate into one framework a representation of the economy by sectors, which bears similarities to alternative methods such as econometrics, together with several features that derive from other fields: information feedback control theory, knowledge of human decision-making processes, and statistical techniques for defining and testing complex system models under conditions of incomplete and inaccurate data. Its capacity to handle "soft" or difficult-to-quantify effects in a dynamic, complex framework allows System Dynamics to represent extreme conditions more realistically. On the other hand, because such a model is designed to operate even when variables take extreme values well outside the range of historical experience, it can produce results from inputs that are unrealistic: for example, if parameters were altered to allow people to exist without food, the model could produce results that reflect the unlikely assumption that no-one would starve without food. Thus, for every case, the model user must be careful to choose realistic parameters that conform to common sense and that are backed by expert opinion and historical data, if available. We have made the conservative assumption of the most optimistic conditions whenever expert opinion and historical data appeared ambiguous or insufficient. As with any computer model, if incorrect values are selected as inputs, then the results will not be meaningful, according to the computer-modeling principle of "Garbage In -- Garbage Out."

The technique we used to guard against this problem involved repeated testing. For each of the influential parameters we tested, the model's results were analyzed over a wide range of values that the parameter could assume. If small changes in an input parameter created wild swings in the outputed variables of interest, then closer scrutiny of the underlying assumptions was indicated, and undertaken.

It was important that the range of parameters we chose for the model's tests of attack scenarios contained none of these sharp effects: although such non-linearities probably do exist in the economy, we cannot know exactly where they lie. By choosing the least drastic, most conservative alternative to such effects, we ensured that our results do not rely on such very strong, but dubious, factors; this in turn increased our confidence in the model's robustness. For every scenario we tested, a range of variables was used. The technique of using a range instead of a single value provides a futher check: if the results are fairly similar over the entire range of variables, it is less likely that the model's results are caused by some accidental effect or an overlooked non-linearity. Under such conditions of conservative, nonextreme assumptions, if the model's behavior indicated that the attack scenario we were testing would cause the economy to collapse, we could be quite certain that reintroducing the many pessimistic (and, we believe, more realistic) assumptions we had omitted would only worsen the picture. It is also important to point out that we have omitted many other factors that would affect the post-attack economy adversely, such as the contamination by radioactive fallout, ecological and climatological effects such as ozone depletion and nuclear winter, and the transformation of domestic and international politics. It seems probable that such factors would make survival after a nuclear attack even more difficult than our conservative estimates indicate, but since we have no dependable and quantifiable way to introduce these effects into the FEMA model, we chose to leave them out, aware of their exacerbating effects.

System Dynamics models such as the FEMA model can represent the economy by sectors. Each sector requires inputs, which are the products of other sectors, and itself produces goods and services used by other sectors. Economic activity is the flow of these input and outputs. It is important to represent the economy by this structure in an analysis of the effects of a nuclear attack for two reasons: first, because different sectors may suffer different degrees of damage in an attack; and second, because industrial products are not interchangeable. In order to distinguish between steel and grain, or machine parts and toys, a model must represent each type of commodity separately. The most detailed models divide the economy into hundreds of sectors. This level of detail is probably not justified in post-attack models because of the many uncertainties involved and because some products can be substituted for. For example, since steel and aluminum can often replace each other, a metals-producing sector might suffice to represent both. But steel and aluminum are only partially interchangeable: aircraft cannot easily be made of steel, nor can locomotive shafts easily be made of aluminum. This implies that aggregating metals, which results in the loss of distinction between different types of materials, would lead to an overestimation of the availability of some crucial metals. This point is especially important in the case in which all steel production is lost but aluminum production capacity is left intact (or vice versa). In the model, the general metals production would fall, and all sectors would receive some part of their usual metals delivery, whether aluminum or steel. Thus the sector aggregation provides a less extreme, more optimistic representation of unbalanced attacks directed at specific sectors. In order to represent each sector separately, the model would have to be many times more complicated. Our solution to this problem is instead to treat the automatic aggregation of sector components as an error on the side of optimism, another conservative condition, since the effects of an unbalanced attack would always be underestimated by our aggregated model. We made a correction for this only in the energy sector, to reflect the unique role of liquid fuels in transportation. Our modifications are explained in the section describing the model structure.

Modeling techniques designed to operate in the relatively narrow, normal range of historical data, can lead to misleading results given extreme inputs, uncertain desired production rates, large fluctuations in prices and availabilities, negative growth rates, or sudden changes. Yet a model of the post-attack economy must operate outside the range of historical data, in conditions that do not correspond to those from which the original data were derived. We were therefore forced to use an approach that is not primarily based on historical data. The System Dynamics technique provided such an approach. While historical data may also be employed in estimating parameters and functions in a System Dymanics model, the primary source of information is the opinion of experts in specific areas. In constructing a System Dynamics model, researchers might interview factory managers and shop foremen as well as economists and industry consultants, to find out how they make decisions regarding such variables as allocation of resources and rates of production. The researcher studies the list of factors that actually influence the decision rules of economic agents, instead of investigating which factors can be mathematically correlated with others. The variables whose behavior they have studied might include inventories, order backlogs, delivery delays, perceived prices, expected prices, expectations of the market's stability, and desired production rates. Because decision-making, rather than its usual aggregate results, is the focus, this technique is probably better suited to represent the behavior of agents in the economy under unusual conditions of low availability of some factors and adequate supplies of others, of extreme price fluctuations and of uncertain desired production rates. While the model is running, these parameters are readjusted every solution interval (usually several hundred times in one run) through changes in their determinants [12].

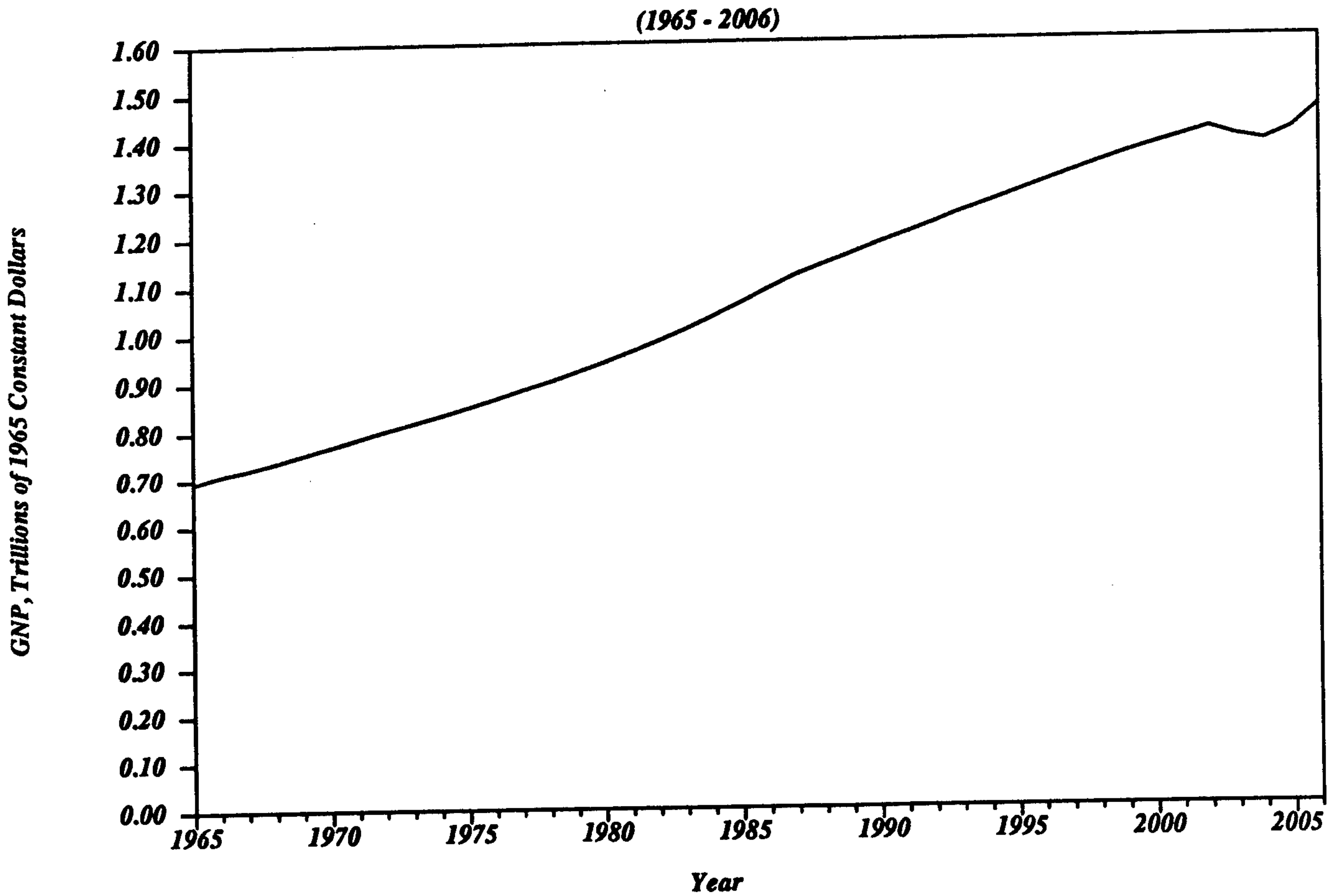
THE MODEL

System Dynamics views an industrial, social, or economic system as composed of three primary components: "states" of the system, rates of change of these states, and information networks. State variables describe the condition of the system and the accumulations of system resources. For example, state variables could include material inventories, labor pools, money, and capital equipment. Other variables representing states include qualitative attributes of system resources, such as the perceptions, attitudes, skills, morale, and health of a labor force. The level of public confidence in the official leadership is another example of a system state. States are affected by rates of change, which represent the flows in the system such as receipt and payment of money, the acquisition and disposal of capital equipment, changes in perceptions, or acquisition of skills. Over each incremental time period, these flows act to change the system states. The third component of a system is its information network, representing data flow, perceptions, judgments, and decisions. Through this complex network, information describing past and current states of the system is used by decision-makers such as consumers, corporate executives, and government officials to formulate their reaction to the changing of one or more system states. Based on this information, the decision-makers take actions that tend to change the rates of change of the system and, consequently, the future states. For example, corporate executives collect information on the supply-demand balance, the trends in the market, and the financial condition of their company and then make investment decisions. Investments create a flow of new capital equipment, which affects the supply-demand balance, the cash flow of the company, the perceived risk, and other factors that determine future investment decisions. Public sector officials also tend to respond in this manner to information describing economic and social conditions.

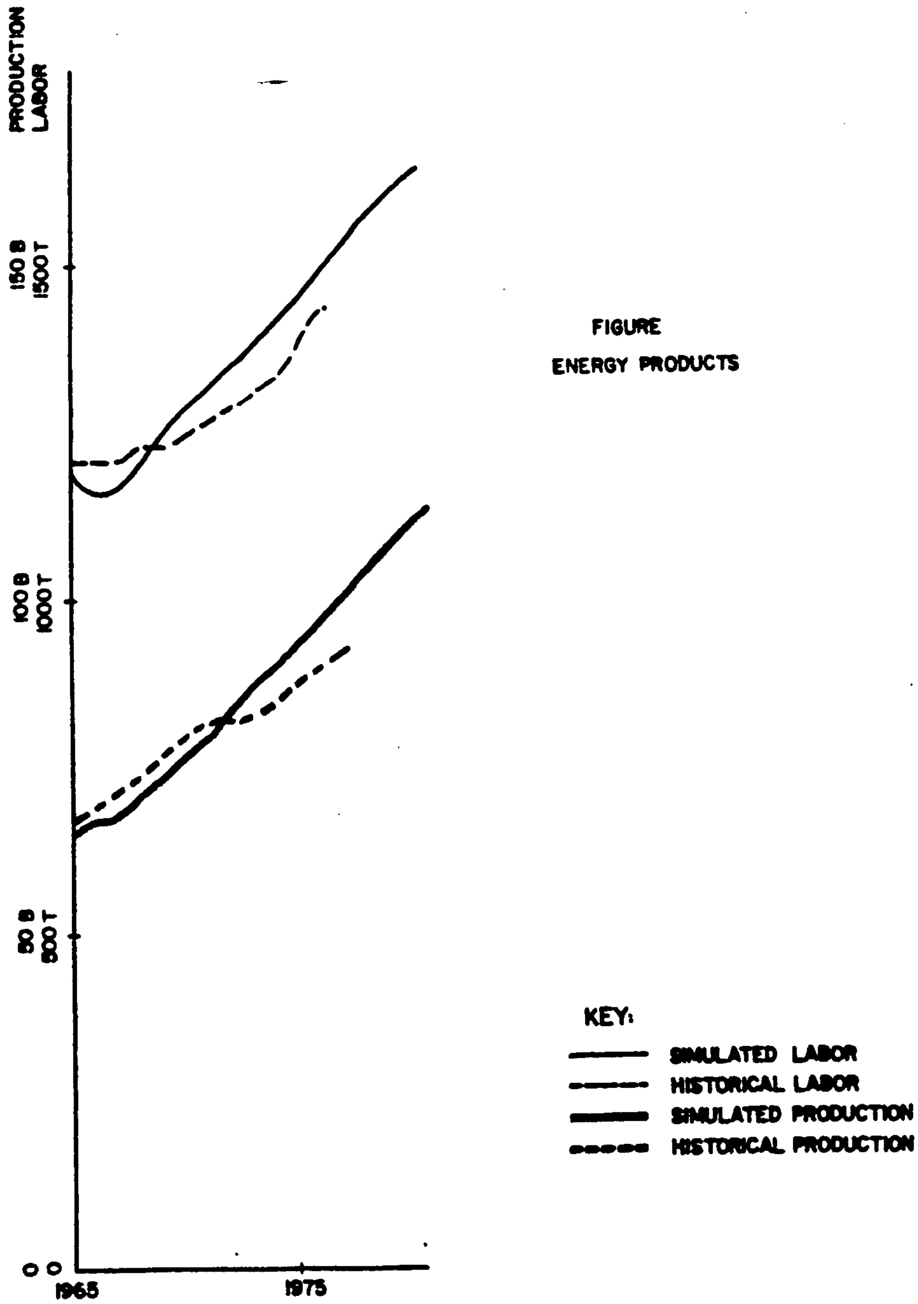
The FEMA model was developed using these relationships, quantified in equations which express analytically the decisions that generate the system's rates of change. The quantification includes explicit representation of the delays involved in collecting data, making decisions, and initiating action. The equations were incorporated into a model which was implemented on a computer and used to simulate and forecast the behavior of the system. Using the model to develop a "baseline" simulation provided a benchmark against which the impact of alternate policies, priorities, or attack scenarios were tested. These alternative scenarios were also used for sensitivity testing, to examine the consequences of changes in parameters or structural assumptions when there was uncertainty about their true value.

To check the model's behavior and consistency, when possible its parameters were derived from actual time-series data of the U.S. economy over the past two decades. The behavior of the model over that time is consistent with the historical record. Because, however, there is such great uncertainty surrounding any nuclear attack scenario, no attempt was made to forecast the precise variations in the peacetime business cycle, or to design the model for traditional economic forecasting. Trends rather than exact values of the variables at specific times were our goal. Nevertheless, model-predicted patterns of GNP growth, overall and by sector, matched the real data rather well. Some of these graphs are reproduced here for comparison.

REAL GNP, WITH NO ATTACK



Graphs of simulated versus historical values for labor and production in several representative sectors.



From Development of a Dynamic Model to Evaluate Economic Recovery Following a Nuclear Attack, Pugh-Roberts Assoc., Inc. (Cambridge, MA. 1980)

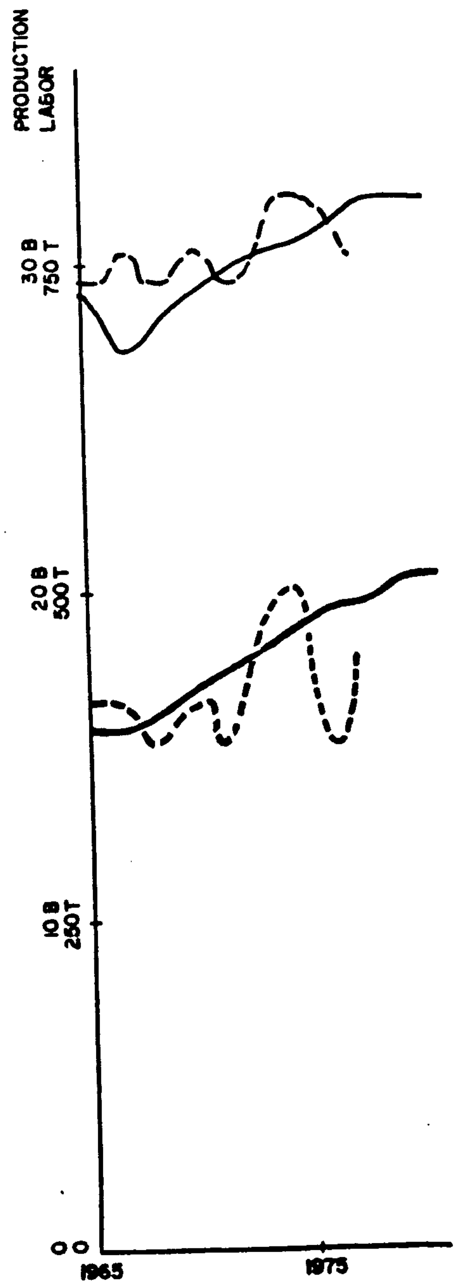


FIGURE
NON-METALLIC DURABLE GOODS

KEY:
SIMULATED LABOR
HISTORICAL LABOR
SIMULATED PRODUCTION
HISTORICAL PRODUCTION

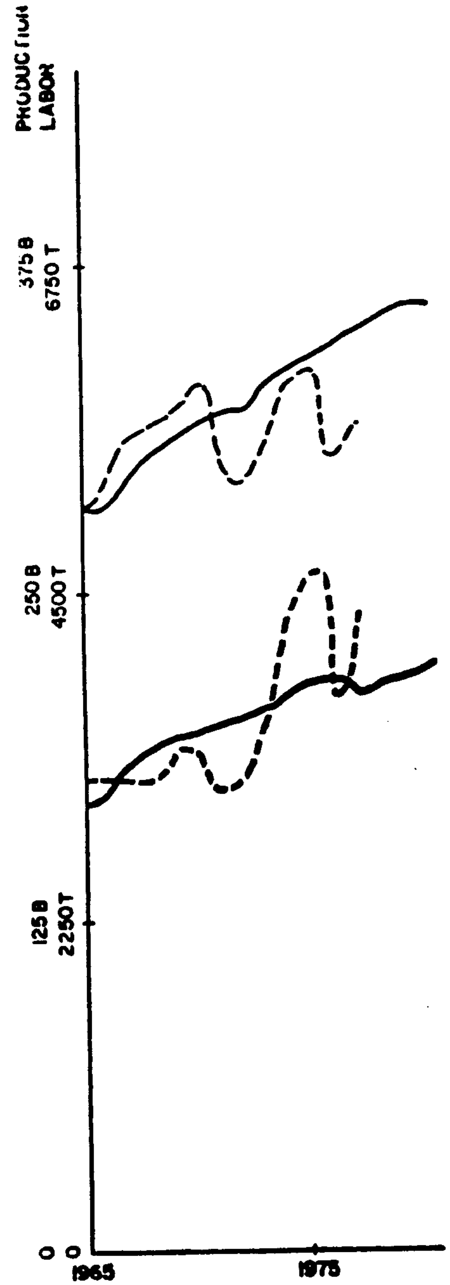


FIGURE
CAPITAL GOODS

KEY:
SIMULATED LABOR
HISTORICAL LABOR
SIMULATED PRODUCTION
HISTORICAL PRODUCTION

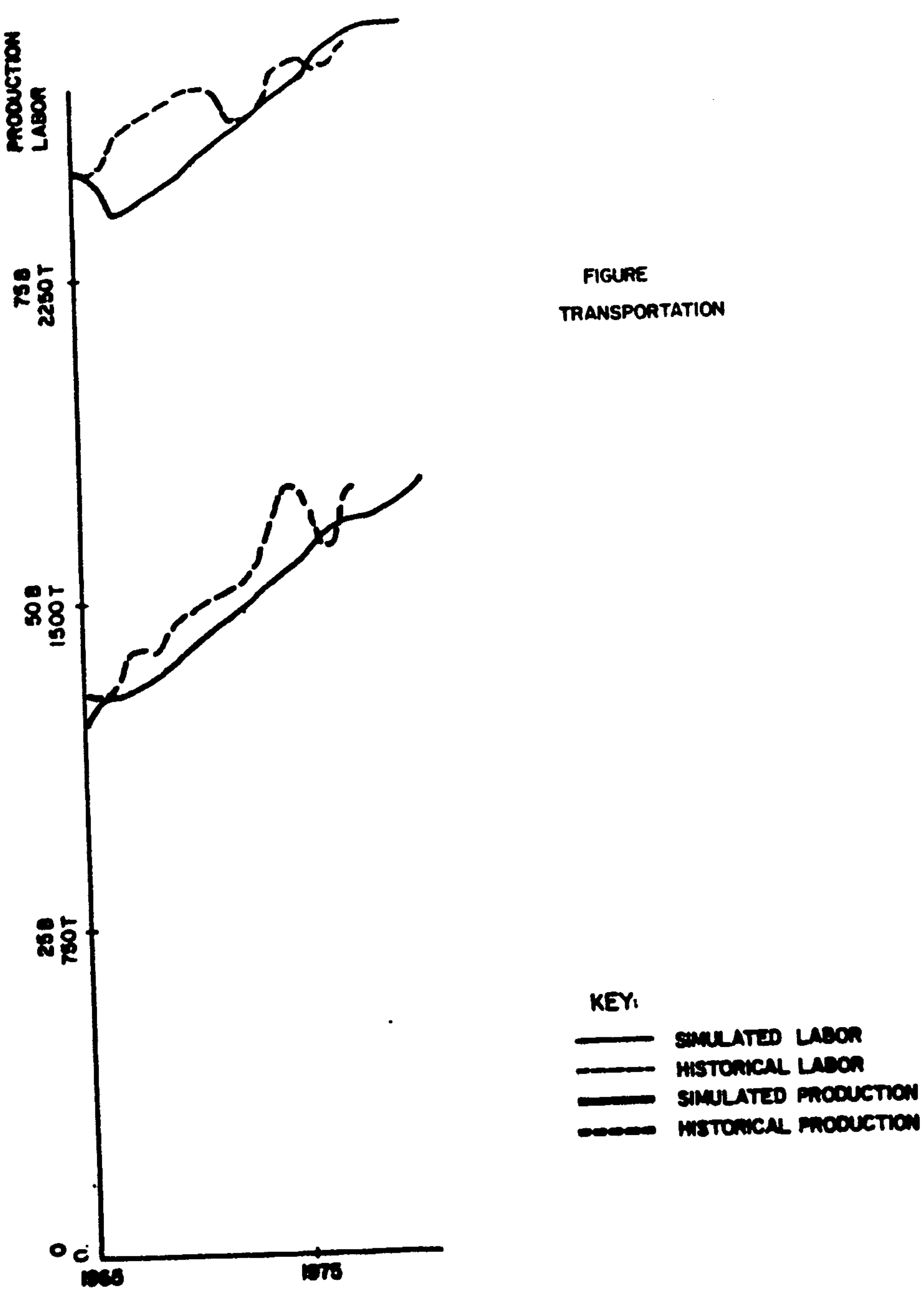


FIGURE
TRANSPORTATION

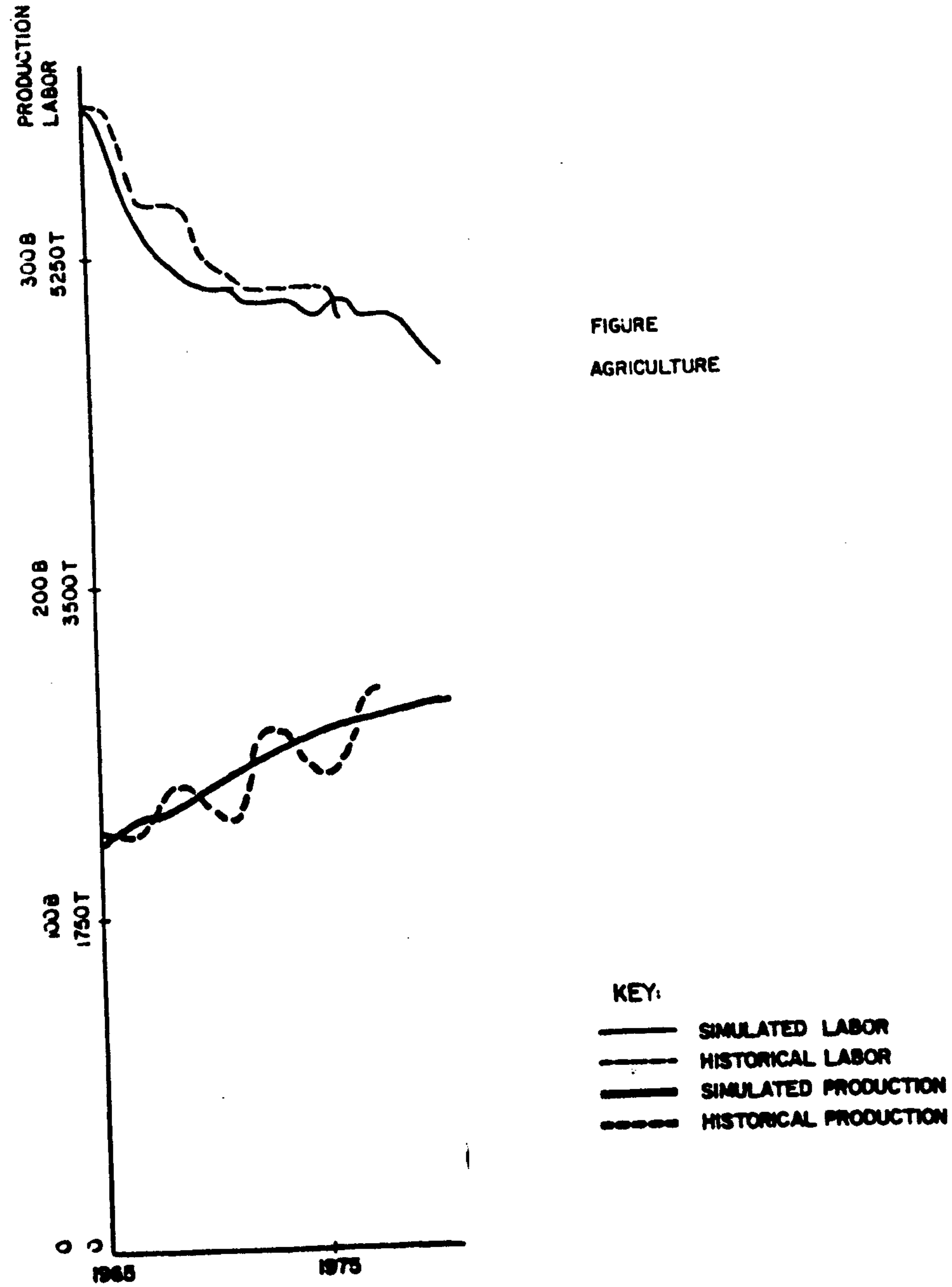


FIGURE
AGRICULTURE

Extensive testing provided a further check of the model. The time-development of key variables demonstrated which components of the economy would be vulnerable to a strategic nuclear attack; tracing through the model's output proved helpful in understanding the causal links inherent in the national economic structure. These links, such as the relationships between industrial sectors, are firm features of the structure of the U.S. economy. Vulnerability of the economy to their destruction cannot be reduced without fundamental, long-term changes in the national economy. Our almost total reliance on petroleum fuels for transportation is something that would take many years to alter, even in the most optimistic peacetime scenarios. Many studies, such as the Office of Technology Assessment's study, U.S. Vulnerability to an Oil Import Curtailment [13], support this fact.

Despite the complexity and robustness of the model, its usefulness lies not so much in the quantitative nature of its predictive capacity and its results, but rather in its value as a tool for analyzing vulnerabilities of critical economic variables. Results of the model's simulations can reveal only probable outcomes, which must be interpreted only in the context of the initial values of the variables such as physical damage, psychological responses, governmental policies, and international trading we chose to represent the conditions generated by various types of attacks.

Model Structure

The large system of hundreds of nonlinear, recursive, time-difference equations that constitute the FEMA model represents the U.S. economy in fourteen sectors. Eleven producing sectors correspond to different categories of industry; the model also includes an import sector, a population, sector and a government sector. Each sector contains a detailed representation of production, planning, capacity expansion, inventory control, distribution of output, finances, supply constraints, employment, pricing, and wage setting. The interconnected structure of the sectors is represented in the input-output structure of the model, with coefficients dynamically updated by changing technology, input shortages, financial constraints, policy inputs, and the adjustment of stocks. The variables that represent psychological responses of corporate planners, consumers, and the labor force are important components of the equations that repesent the U.S. economy.

The fourteen sectors fall into three areas: production, product transfer, and consumption.

Production	Product Transfer	Consumption
(Imports)	Services	Government
Agriculture	Government	Population
Capital Goods	Transportation	
Construction	Medical/Emergency	
Consumer Goods		
Energy Products		
Metallic Durable Materials		
Non-Metallic Durable Materials		
Non-Fuel Consumable Materials		

Up to 23 industries comprise each component sector. Together, these sectors account for the 80 or so national industries (classified by the Survey of Current Business sector designation) [14].

Each of the model's fourteen sectors is aggregated. For example, the Metallic Durable Materials sector includes the following industries: iron and ferro-alloy ores mining; nonferrous metal ores mining; primary iron and steel manufacturing; primary nonferrous metal manufacturing; and scrap, used, and secondhand goods. These industries are all related, and require similar materials, services, and expertise. Their aggregation is necessary to simplify and speed the calculating requirements. By necessity, such aggregation obscures the "fine structure" of economic activity and has limited our ability to formulate hypothetical bottlenecking attacks that would target only one industrial sector, such as non-ferrous metals production. As discussed earlier, such aggregation, although a simplification, tends to overestimate the economy's ability to recover from an unbalanced nuclear attack.

Modifications

In the energy products sector in particular, this aggregation combines several quite diverse elements of the economy, some of which are much more critical than others for post-nuclear-attack recovery and some much more vulnerable to nuclear attack than others. The representation of energy products -- which combines electric, gas, water and sanitation services, crude petroleum and natural gas extraction, petroleum refining and related industries, and coal mining -- can result in an underestimation of the impact on the economy of reducing the availability of petroleum (or, equivalently, of liquid fuels) to near zero. We therefore modified the model to correct this shortcoming, since we wanted to study in detail the effects on the U.S. economy of the collapse of the liquid fuels supply.

In an attack scenario in which petroleum refining, pipeline pumps and nodes, ports, terminals, and reserves are targeted but other components of the aggregated energy sector are almost completely undamaged, the final drop in output capacity of the entire energy sector would be only 30%, since petroleum accounts for 30% of the sector's total output. The model, as it stood previously, would have reduced the energy available to the rest of the economy by 30% in an undifferentiated manner; it also would have reduced the availability of electric and sanitation services by 30%. This did not realistically reflect the importance of petroleum to national economic activity. Such an absence of discrimination would critically affect predictions of the performance of the transportation sector. In the economy today, transportation is almost completely dependent on petroleum, to the extent that any drop in petroleum input results in a commensurate reduction in transportation availability. Following an attack against all petroleum production and supply, the means of transportation -- cars, trucks, trains, ships, barges, and airplanes -- would suffer a 97% shortfall in required energy input. Other industries that are not primary consumers of petroleum would appear less dependent on this fuel. Since, however, every industry is dependent on transportation, production in every industry would dwindle without the means to transport materials, work force, products, and non-petroleum energy. It was essential then for our analysis to disaggregate the liquid fuel component of the energy sector in our simulation program.

Our changes to the model reflected the unavailability of liquid fuels through a proportional "disconnecting" of transportation capital. Without liquid fuel imports, transportation capital is "disconnected" from the rest of the economy, and so is operationally useless although it physically still exists largely intact. The transportation capital can be "reconnected" — that is, brought into use again — by directing, immediately after the attack, resources for refinery reconstruction, alternative fuel development, or to alternative transportation capital manufacturing. Developing these three options would require similar expertise, materials, and manpower; consequently, the resources required for each of these three developments to produce a given amount of transportation equipment are similar. Thus for a given amount of resource investment, which of these three options is chosen does not affect drastically the rate at which transportation capital is reconnected, since roughly the same amount of transportation capital would be returned to use by any choice. In our modification to the model, a single variable represents the aggregation of refinery reconstruction, alternative fuel development, and alternative transportation capital manufacturing in order to simplify the calculation. In addition, we assume in the analysis that follows that the most efficient paths are chosen and that none of the resources are wasted. The most important of our optimistic biases here, however, concerns investment in new energy and transportation facilities: following an attack on transportation fuel facilities, we assume that any extra effort to develop the capital facilities or equipment needed to reintegrate transportation equipment (almost all of which had been rendered unusable by the loss of liquid fuels) is made at no cost to the economy. In other words, the extra investment required to increase the availability of transportation does not divert investment from any other sector -- clearly an extremely optimistic assumption. As in the real economy, the level of investment is linked to economic preformance (a given fraction of total available investment is allocated to transportation;

thus, more investment is allowed if GNP is high). Since we could not modify the entire model to reflect intensive investment policies more accurately, we chose to make this very optimisitic representation of cost-free investment. In reality, such a policy would of course exact high economic costs, which in turn would reduce the rate of increase in the production capacity of other capital-intensive sectors.

Our second modification to the original FEMA model disaggregated the imports and exports. Orginally, all imports and exports were represented by a single variable in the FEMA model, called their "availability." We replaced this variable in the model with sector-specific availabilities. The destruction of all ports, petroleum terminals and pipeline nodes would immediately reduce the level of energy imports to near zero, but would possibly allow imports of other goods that do not require such specialised transportation and storage systems. In the months following an attack directed at energy and energy-imports facilities, the availability of fuel supplies, personnel and expertise would be reduced to near zero, since the ports are destroyed, as are many nodes of the transportation network. Although ports could be reconstructed or alternative techniques for importing materials could be developed, this would take many months, and the volume of imports that could be handled would be severely restricted.

Our new formulation for import availability gave us the ability to restrict imports to a given fraction of their pre-attack volume. This fraction we specified together with other parameters for each model run; and the entire mechanism for restricting imports was only used for scenarios in which imports would be physically restricted. In all cases, we assume that there is an increasing level of imports in each year after the attack and that imports would no longer be limited either 5 or 10 years after the attack. Although this increase in import levels would in fact require significant investment to rebuild ports, the model allows imports to grow without the diversion of any investment capital.

Psychological Effects

In our testing of the model we found that the psychological effects variables in the program had unexpectedly strong influence on the outcome of various attack sceneria. The psychological effects sector of the model attempts to represent those changing attitudes and sentiments among the population that would have a significant effect on the population's economic behavior. As we have described earlier in this chapter, we often chose to omit the effects of psychological influences on economic behavior, since they are so difficult to predict and quantify. For example, we did not assume adverse psychological effects in the baseline case, but we consider this omission to be perhaps the most optimistic assumption in the whole study.

We describe here how the psychological effects sector relates the principal measure of the psychological state of the population to the behavior of the economy as depicted by the FEMA model to show the mechanisms by which this factor influences the behavior of the economy after an attack. The three main components of the psychological effects sector are the level of confidence among the general public, the degree of frustration of the public, and the responsiveness of the government bureaucracy in executing official policies; each of these factors depends in turn to the performance of the economy, the activities of government officials, and the trauma of a nuclear attack. [15]

Public Confidence

The most important psychological factor in the model (and the only one we will discuss in detail) is the level of public confidence. It measures the degree to which people believe that their productive effort and investment of assets will produce future benefits of commensurate value. Three important economic variables are affected by the level of public confidence: labor productivity, the level of participation in the workforce, and consumption (which directly influences savings).

The productivity of the labor force is influenced by the morale or confidence of the workforce -- for example, high morale generates higher productivity during wartime. If public confidence declined to very low levels, some people would begin to withdraw from organized productive activities and engage in efforts to assure short-term survival, such as scavenging and looting, which would contribute little to the gross national product, or GNP. That is, the larger the attack, the more likely it is that people will choose to flee the cities and industrial centers rather than try to rebuild them.

The rate of consumption is another factor influenced by public confidence. If people were satisfied with their current standard of living and optimistic about how well the economic system is functioning, they would be willing to consume a smaller portion of their income in order to invest for additional future benefits. On the other hand, if the per capita income were near the subsistence level, or if the perceived likelihood of receiving future benefits from investment were low, individuals would tend to consume more of their income and save less of it. As the next section demonstrates, investment is an important determinant of recovery.

There are four fundamental factors which could combine to generate low public confidence: GNP per capita, perceived adequacy of resources for survival, the trauma resulting from perceived death and destruction of the nuclear attack, and the qualities of the leadership. Public confidence is influenced by how favorably real GNP compares to the traditional value of GNP per capita. A level of GNP per capita that was high compared to the traditional level would buoy public confidence, and a low level would depress public confidence. Regardless of the absolute level of GNP per capita, the direction and magnitude of change in GNP — its rate of growth or decline — affects public confidence independently; rising GNP would boost confidence, and declining GNP would lower confidence. In extreme cases of low GNP per capita, such as may occur in the post-attack environment, people may not be able to consume enough to survive. In this desperate situation, the inadequacy of resources for survival, in addition to increasing the population's death rate, would sharply lower the level of public confidence of the survivors.

The final fundamental influence on public confidence is the lingering trauma from the widespread death and physical destruction that would affect the survivors of a nuclear attack. The psychological paralysis that would doubtless immediately follow such an attack would reduce peoples' ability to perform economic tasks. Confidence would remain depressed until people recovered from the shock of the deaths of the people they cared about and the devastation of their nation.

While the above factors fundamentally determine public confidence, charismatic official leaders could temporarily boost the morale of the population. Yet if the nation's leaders have themselves been killed in the attack — or if nationwide communication has been destroyed — national leadership will have little effect. In large enough attacks, such as the 60/40 attack, even statewide leadership may be rendered ineffective, causing the nation to fragment further, and public confidence to plummet.

Representing a Nuclear Attack

When the FEMA model is used to analyze the economic consequences of specific nuclear attacks, the immediate physical effects of the weapons are one of the inputs to the model. Such factors as the availability of imports and the quantity of investment diverted to transportation or energy equipment redevelopment are also inputs to the model, initial or boundary conditions that can be varied to implement the various attack scenarios we have explored. The physical damage to each of the fourteen sectors is represented separately, and consists of three components for each sector: the fraction of capital equipment lost, the fraction of buildings lost, and the fraction of inventories lost. Where the capital equipment and inventories are at least as delicate as the buildings that house them, such as in electronics manufacturing or petroleum refining, we made the assumption that all three components are destroyed in the same proportion as the buildings. For industries with relatively robust equipment, such as primary metals production, we assumed that only half the equipment and inventory inside destroyed buildings is destroyed. As we have demonstrated in Chapter One, use of the 5-psi contour as the limit of building destruction -- which we have followed -- tends to underestimate the extent of damage. So our assumptions are once again optimistic.

The model's inputs also include the fraction of people killed and injured in the attack. Other components of immediate damage are the fraction of motor vehicles and household buildings destroyed, which is usually set to include all those within the 5-psi contour.

The attack scenario also determines whether or not imports are available to the United States. These are specified by sector, and their availability after a nuclear attack could depend on two factors: international political relations and the state of the nation's ports, airports, train lines, and highways. Even within very favorable international political circumstances (which is the assumption we have used in all scenarios), it would become very difficult to import products such as petroleum if all ports were destroyed, the pipeline system damaged, and major cities -- which serve as the nodes of the air and rail networks -- devastated. The addition of a few extra weapons would cripple Canada and Mexico (and both nations would be severely affected by the single EMP burst over the U.S.). In this case, immediately following the attack, neither electricity from Canada nor oil from Mexico would be available. Without these energy sources, which the U.S. uses extensively even in peacetime, the nation would be left with virtually no energy supplies.

It may be possible to import some kinds of non-bulk food and industrial products by means of airplanes light enough to land on highways or local airstrips, since airports in most major cities could be destroyed. Such imports might also be brought in by ships that can be unloaded onto smaller boats, which in turn may be able to discharge cargo at shallow, non-port coastal areas. Since ports would be prime targets in such a scenario, however, shipping berths would be destroyed, and the surrounding land could very well be irradiated, making it very difficult to rebuild ports soon after the attack. In addition, worldwide refined petroleum availability would plummet following the destruction of Mexican, Canadian and American refineries. To test the impact of imports on the behavior of a post-attack economy, for each of the attacks, we have used several scenarios, each allowing varying amounts of imports. Often, the results indicated that imports would prove useless because the attack would have crippled the internal transportation system, and therefore imported material could not be transported where needed.

In the scenarios we tested, the nuclear attack is immediately followed by the reconstruction effort. The form of the attack we postulate takes the most optimistic form: there is no more fighting after the single, swift attack, and if foreign trade is physically possible, then goods can be imported and exported. The model generally depicts the behavior of the economy for the twenty years following the attack, and the dynamic variables are readjusted by the model for every three-week period during that time.

Interpretation of Results

The model produces both numerical and graphical results. Graphical results are more informative, visibly demonstrating the dynamic behaviour of key variables. The model can depict the behavior in time of any one of its variables. The GNP graph is the most useful summary of economic activity and provides the first indication of whether or not the economy is recovering. Typical GNP graphs may be found in the next chapter. Eleven sets of graphs give a detailed picture of each of the model's sectors. For each sector, the model produces plots of production, demand, capacity, and potential production (as determined by labor availability), together with a set of variables that describe the adequacy of important factors for the particular sector, such as energy products, transportation, services, and non-fuel consumable materials. In the Appendix, we reproduce, for a given attack scenario, a representative set of graphs for several sectors and discuss the signficance of each of the model's outputs.

The numerical value of any variable can be printed out at any time in the model's run. But since the actual value of any of these components will depend on a multitude of factors, each of which is subject to a measure of uncertainty, exact quantitative results are in fact also necessarily imprecise. The graphical results are far more informative, since it is the trends rather than the absolute level of economic behavior that are more reliable and instructive, and can be seen best in their graphical form.

The model's results give an indication of the response to a nuclear attack of the national economy as an integrated activity. The failure of the national economy to function as a nationally integrated entity is depicted by the model as a decline in production, eventually leading to collapse. However, even though the model may indicate that the national economy has collapsed, it is possible and in fact probable, that there will remain pockets of self-sufficient, regional or local economic activity. Yet such scattered elements of economic activity would not resemble the economic structure existing today. Thus the model's prediction of collapse following the failure of the interdependent links in the national economy is consistent with our basic definition of the U.S. economy as a nationally integrated structure.

CHAPTER FOUR

TESTING THE MODEL

Extensive tests of the FEMA model reveal the vulnerability of the U.S. economy to small, well-planned nuclear attacks. In our work with the model, three kinds of tests proved important: tests that revealed the model's structure, sensitivity tests, and investigations of the results of various attack scenarios.

Our preliminary explorations of the model focused on its structure and behavior. These tests revealed important characteristics of the model, such as its tendency to underrepresent damage following a very lop-sided attack. This was due to the model's aggregation of many sub-sectors of economic activity, which are represented together by a single variable. The attack scenarios we wanted to test, however, involved destruction of only a few of these sub-sectors. Thus the effect of such attacks was "averaged out," and the results in individual sub-sectors were obscured by the program. To correct for such problems in instances where they would severely misrepresent effects of attacks we were considering, we made several modifications, such as the one that separated liquid fuels from the other constituents of the energy sector.

Other tests, which measured the model's sensitivity, allowed us to analyze the dependence of the model's results on initial assumptions and boundary conditions -- for example, the effects of varying such inputs as the availability of imports and the psychological reaction of the population to a nuclear attack. Finally, the model was tested with inputs derived from calculations of the damage resulting from various nuclear attack scenarios. To provide further tests of the model's sensitivity, these attack scenario inputs were used in conjunction with differing values of key parameters, which had been identified as important by the earlier sensitivity tests.

The tests we describe in this chapter demonstrate the effects of varying those factors that were identified as being significant during the sensitivity tests of the model. It is important to bear in mind that all our results reflect initial assumptions that are probably quite optimistic. There were other potential influences that we could not test -- components that are perhaps more fundamental to the model. Such factors exert influences that are so integral to the economy that they are impossible to model separately; yet because of their fundamental influence, these are likely to be the most powerful determinants of economic behavior. For example, the model assumes that the networks responsible for communicating information between all sectors of the economy remain intact. The entire model continues to behave as if each agent operating in the economy had access to the information he required. Entire sections of the model thus are driven by these optimistic assumptions. Negative effects that could result from damage to some fundamental, influential elements of the economy were neglected, since it was extremely difficult for us to represent within the model the effects of their impairment. The financial system provides an example of this weakness: following the attack, the model assumes that the major features of the financial system remain intact, that financial records and computer information systems are undamaged and that the monetary system continues to operate. An opposite view has been presented by some experts, who envision the collapse of the banking system and a return to the barter system [1]. Because they are so integral to the economic system, however, it is impossible to separate such features from the structure of the economy in order to evaluate the impact of even their partial destruction. The model parameters therefore represent the continued functioning of such key elements of the economy as information networks and banks, even though it is quite probable that this assumption is unrealistic.

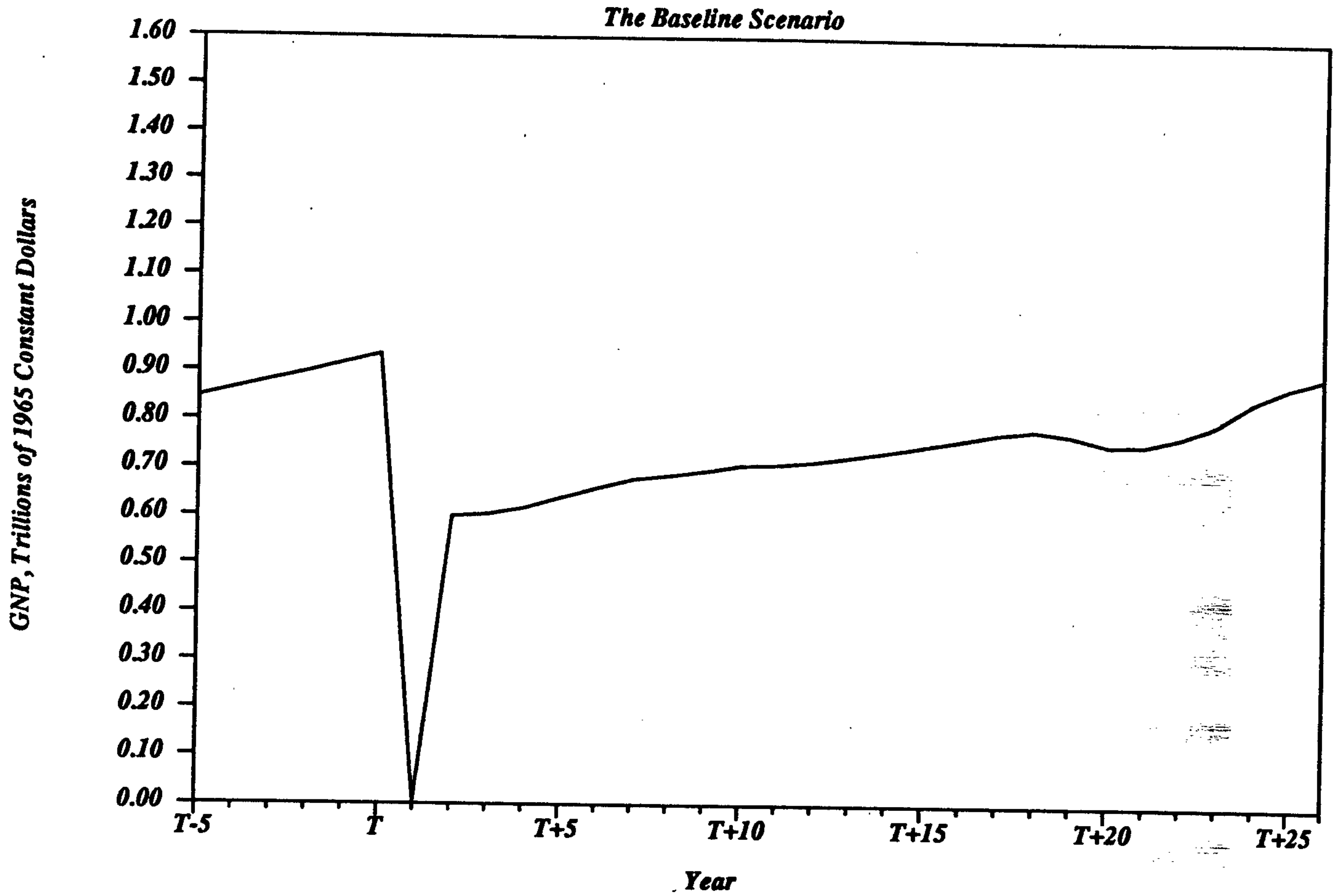
Despite these unavoidable conservative assumptions, the model indicates that even relatively small nuclear attacks targeted on energy facilities and additional crucial elements of the economy would have catastrophic results. The results we present in this report of course depend on the parameters that we chose for each case. Our tests included a wide range of values for many factors; however, since each of the fourteen sectors contains 600 variables, we could not analyze the model's sensitivity to the variations of all the variables. When testing various effects in isolation, other influential variables were assigned conservative default values (default values are those assumed by the model if no change is specified, that is, they are the values the variables would have in a normal, undisturbed economy). For example, built into the model are a set of rules governing the allocation of scarce resources. The model assumes that when available energy supplies cannot match demand, first priority is given to the energy and transportation sectors. This rule represents a policy designed to improve the economy's chance of recovering. If the energy sector did not receive enough fuel to enable it to continue producing energy, the nation could slide under the "energy threshold" we discussed in Chapter Two. A similar situation could develop in the transporation sector. To avoid such traps, allocation rules automatically select optimistic conditions. When we tested less far-sighted approaches to allocation (such as assigning materials in quantities proportional to the level of demand in each sector -- a policy that might not seem unreasonable to the post-attack government), the model depicted economic performance that was far worse.

In many other instances, "built-in" optimistic assumptions operate in the model. For example, the model incorporates the manner in which managers and foremen control their inventories and rate of production. In peacetime, following an apparent change in demand for their product, they delay their reaction (change the rate of production or shipping, for instance) until the trend has been observed for several months. Since demand, like most economic variables, normally fluctuates considerably about its average value, this behavior is entirely rational. Yet, following a nuclear attack, it is unlikely that the same decision rules would apply. Information about demand might be unreliable, and managers might wait even longer before making adjustments. They might not know how many factories had been destroyed and how much demand there would be for their products; perhaps they would refrain from making large adjustments to their production rate until the situatation became clearer. In the model, however, some sort of centralized authority is assumed to be operating after the nuclear attack, and it is assumed that these decision-makers are instantly informed about the extent of the damage across the country and adjust their operations accordingly. This assumption of perfect knowledge is an optimistic one, but is necessary because there is so much uncertainty about the post-attack economy.

Another key assumption we have made produces similarly optimistic economic effects. All demand for U.S. exports is set at zero following the attack, while the U.S. is assumed to be able to import foreign goods (within the physical restrictions). In the very vunlerable period immediately after the attack, the ability to import without having to export allows the U.S. to make maximum use of all its productive capacity for recovery. As the nation recovers, exports can be traded for needed imports, but the built-in allocation rule ensures that, under conditions of scarcity, export demand does not divert products for which domestic need is pressing (in such a case, the export sector would receive a fraction of the product it demanded). These assumptions could correspond to the scenario in which the rest of the world is not affected by either the nuclear attack or the U.S.'s economic problems -- clearly an optimistic scenario.

The importance of variables was explored in extensive sensitivity tests. The graphical output from representative sensitivity tests is presented in this chapter. Plots of GNP (Gross National Product) are used to summarize the behavior of the fourteen industrial sectors, since GNP is the sum of all of the economy's products. Where GNP is compared to normal levels (such as when we give a percentage of normal production), it is the pre-attack value that we are using as the standard for comparison. If projected production is instead used as the standard, the post-attack GNP would appear even smaller in comparison, since in this case it would be calculated with respect to the projected GNP that the national economy would have achieved that year had it continued normally. Similarly, when we discuss how long it takes the economy to "recover," we generally are referring to the period of time it takes the national economy to attain its pre-attack level of production (for our purposes, per capita GNP is not a reliable indicator of economic performance; if the population fell to 25 million, and GNP shrank correspondingly, the economy would have been

SENSITIVITY TESTS



The plunge of the GNP to zero at year "T" reflects the tremendous physical loss of production, capital, and inventories, which must be written off (subtracted) from the remaining production for that year. This zero value for GNP is essentially an accounting artifact, stemming from the method by which GNP is calculated. In contrast, actual collapse of the national economy is indicated by GNP remaining at or near zero for an extended period of time.

fundamentally transformed from its current nationally-integrated structure). If instead we wish to calculate the time it takes for the economy to reach the levels it would have attained in the absence of a nuclear attack, the recovery time would be much longer — in many cases, the economy would simply not recover in this sense, but would remain at a lower plateau for a period of time too long for the model to predict with any confidence.

SENSITIVITY TESTS

We ran over one hundred tests of the model's structure and behavior before producing the results that appear later in this chapter. For this sensitivity testing, we assumed a scenario in which the nuclear attack results in a 40% fatality rate among the population and an across-the-board reduction of 40% in the output of all fourteen economic sectors of the model. We call this the "40/40 baseline attack." These tests revealed several characteristics of the economy that are significant, if only because they are unexpected or counter-intuitive. In this section, we present four key findings of our sensitivity tests.

We first consider the baseline attack scenario -- which corresponds, as noted, to the death of 40% of the population and the destruction of 40% of all capital, buildings, and inventories in each sector, and a reduction of 40% in import availability, ignoring psychological effects. The results (depicted in the first sensitivity test graph of this chapter, labeled the "baseline scenario") were as expected: following the attack, GNP plunged by about 40%, but then embarked on an upward climb at a fairly constant rate of growth, to give a return to the pre-attack level of GNP in about 25 years after the attack. In year "T," when the attack arrives, GNP plunges to zero, reflecting the tremendous physical loss of production, capital, and inventories, which must be written off (subtracted) from the remaining production for that year. This zero value for GNP is essentially an accounting artifact, stemming from the method by which GNP is calculated. In contrast, actual collapse of the national economy is indicated by GNP remaining at or near zero for an extended period of time. From our test, it became clear that the first year or so is the crucial time. In this case, collapse is averted because production can be resumed before inventories are exhausted. Yet, for less evenly balanced attacks, including ones that were much smaller than the 40/40 scenario, we found that collapse could occur at the end of the one- to three- year period of vulnerability. Such results are presented in the next chapter. The 40/40 baseline attack is of course only a theoretical attack we are using for demonstrative and testing purposes, though in fact many previous studies of the effects of limited nuclear attacks use a scenario in which roughly 40% of the nation's manufacturing capacity is lost [2].

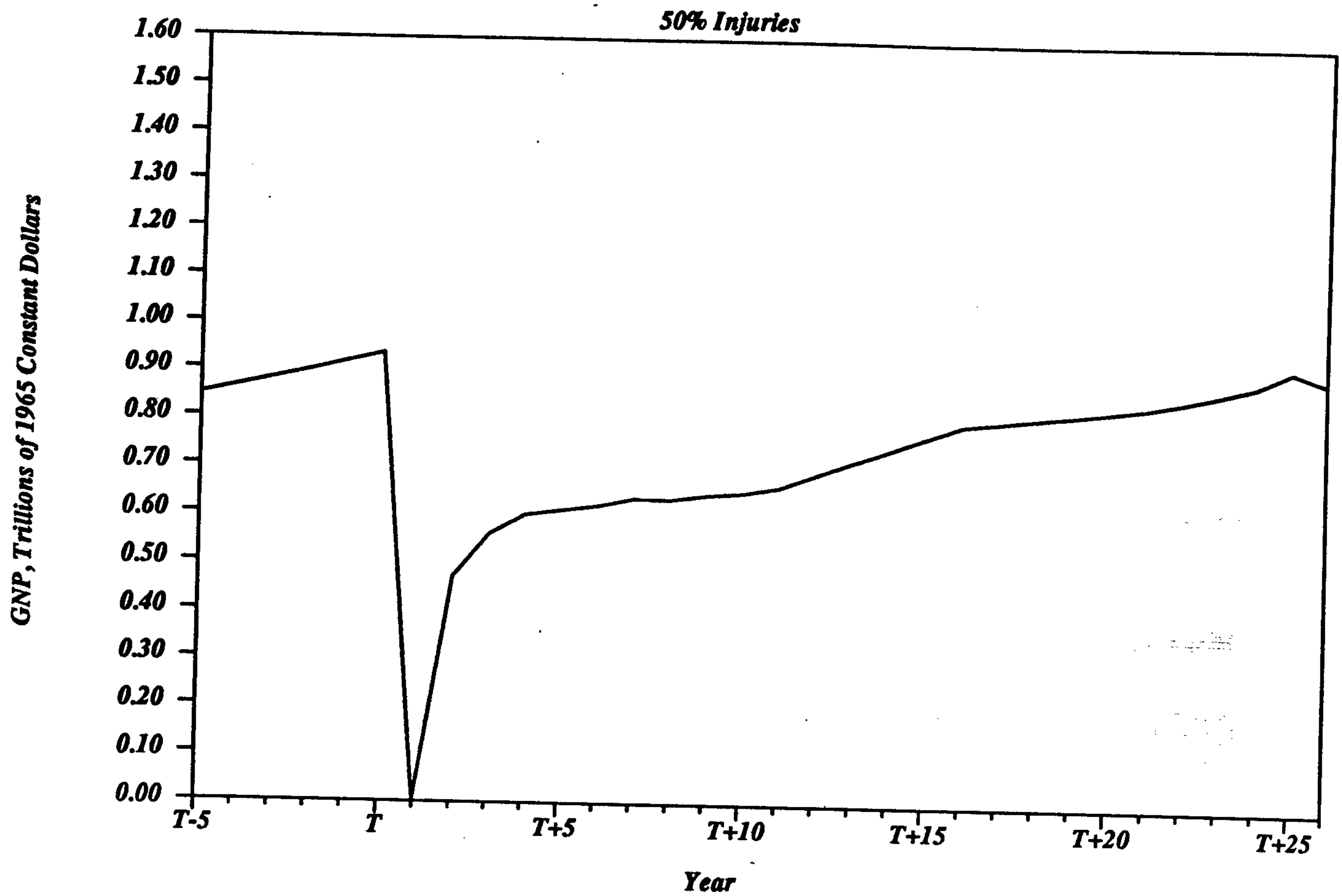
We describe here some variables which proved to be signficant in determining the output of the model in these sensitivity tests.

1. The Proportion of Injured Survivors

Economic performance is depressed considerably if the parameters in the baseline case are altered to reflect a higher proportion of injuries rather than outright fatalities. This is shown by reducing the death rate from 40% to 20% (see the second sensitivity test graph, labeled "50% injured"). In such a scenario, GNP is significantly lower than in the

GNP, Trillions of 1965 Constant Dollars

SENSITIVITY TESTS



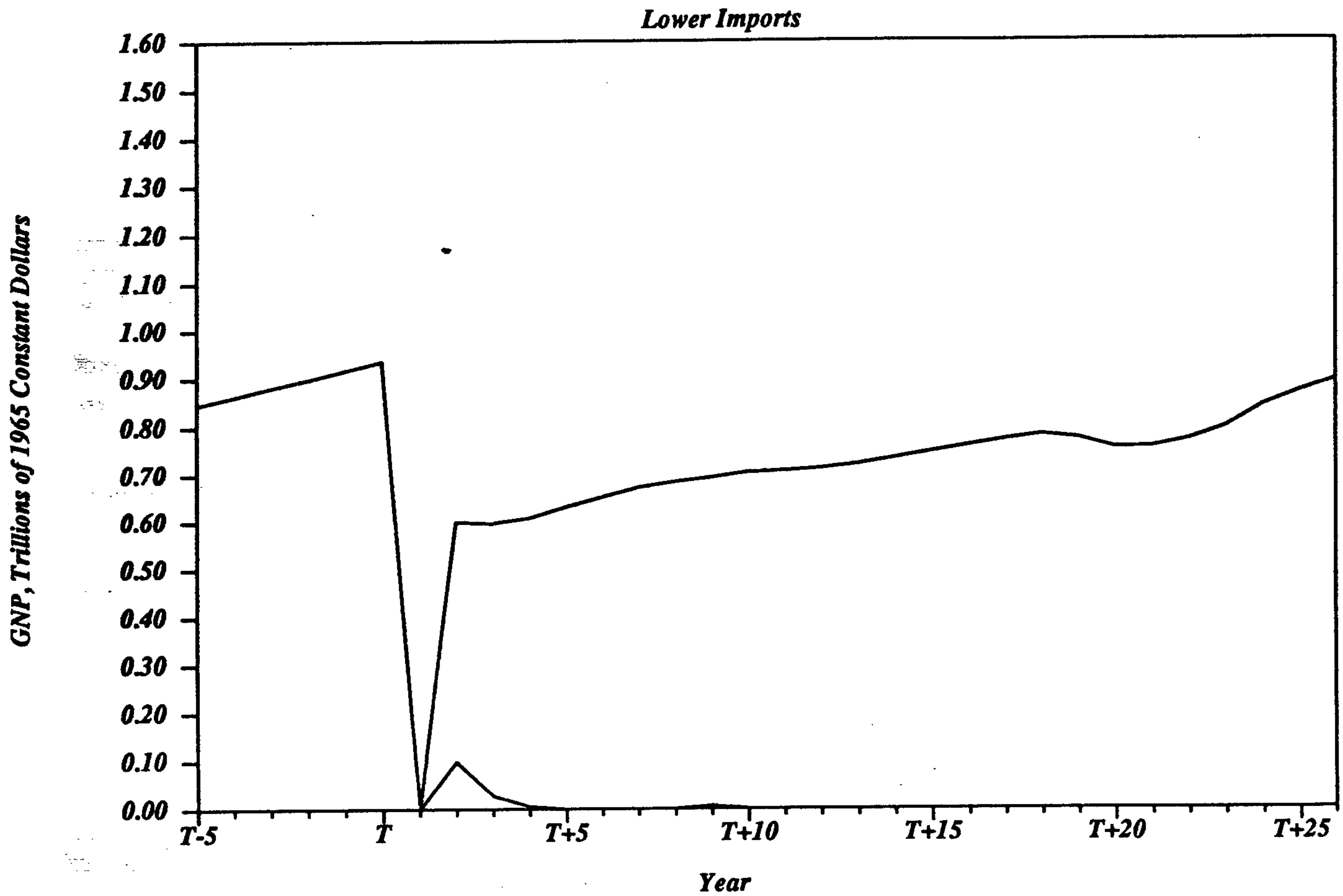
baseline case -- especially in the decade following the attack. This behavior is somewhat surprising: for although some of the injured people do die of their injuries in the months and years following the attack (the death rate from injuries is determined by such factors as the availability of medical care, the quality of the diet and the adequacy of housing), other injured people recover and enter the workforce, and the increase in number of workers normally improves economic performance. Yet we find that in the years immediately after the attack, injured people exert a considerable drain on the economy. They consume food, housing, and health services without contributing to production. They demand daily care that removes healthy people from the workforce. In addition, the extreme demand for medical services they generate puts an enormous strain on the medical sector. Officials in this sector perceive the inadequacy of their sector's capacity (hospitals and medical equipment, for example) to deal with the high levels of demand, and so, naturally enough, order more capacity — a request that can be filled only at the expense of some other sector, unless triage at the national level is opted for early on in the recovery period.

In the absence of triage, however, by the time the medical sector has succeeded in increasing its capacity, many of the people who required medical services have died, and that sector is left with an excess of capacity for over fifteen years while other sectors suffer from a shortfall of capacity. By the end of the second decade after the attack, few injured people are left, the majority having either recovered or died. The medical sector's capacity has reached levels close to demand, and the performance of the economy begins to improve compared to the baseline case. Yet the early years of unstable behavior (GNP is about a third lower in the first post-attack year) indicate how damaging the combination of low fatality rate and high casualty rate can be. When combined with other factors that cause metastable behavior in the early post-attack years, such an effect could contribute to economic collapse. Had psychological effects been included in this scenario, the high injury rate would result in lower morale and lower productivity. Some able-bodied workers would stay home from work to tend their sick relatives rather than obey back-to-work orders; other workers, strained by the presence of large numbers of the infirm, might become more disillusioned with the leadership. The results would seriously worsen economic performance.

2. Import and Export Rates

We next investigated the results of allowing differing quantities of imports and exports to be brought into and out of the country. As we described earlier in this chapter, demand for exports drops to zero following the attack, and so it is assumed that the economy does not initially have to sustain the burden of exporting domestically needed products. In the baseline attack, in order to keep the conditions "balanced," we allow the U.S. to import required goods at up to 60% of its preattack import levels during the first year. This percentage grows to 100% in five years. In two of these tests, we cut imports to 0% in the initial year, growing to full availability five and ten years after the attack respectively. In the first of these cases (shown as the top curve in the sensitivity test graph labeled "lower imports"), the model showed that the behavior of the GNP did not change signficantly. This behavior reflects the fact that, since the scenario tested here is a very well-

SENSITIVITY TEST



Imports return to normal in 5 years (top)

Imports return to normal in 10 years (bottom) balanced attack, demand and supply are uniformly lowered and imports are not the most crucial factor in determing recovery. Nevertheless, if import levels remain low for several years -- the second scenario posits import availability growing annually by one-tenth the pre-attack volume, so that it reaches half the preattack level in five years -- the economy collapses in a few years (as shown in the bottom curve of the "lower imports" graph); this indicates that there is a minimum level of imports required to sustain recovery, even in this balanced scenario.

3. Liquid Fuel Availability

The third effect that we studied in the context of the 40/40 scenario was that of reducing liquid fuel availability. In this set of tests, we postulated that this attack was specifically targeted at liquid fuels, causing the availability of fuels for transportation to plummet immediately after the attack. We modeled this shortage of fuels by "disconnecting" differing fractions of the surviving transportation capital -- that is by, making it temporarily unusable until investment in either the energy or transportation sector brings it back into use again.

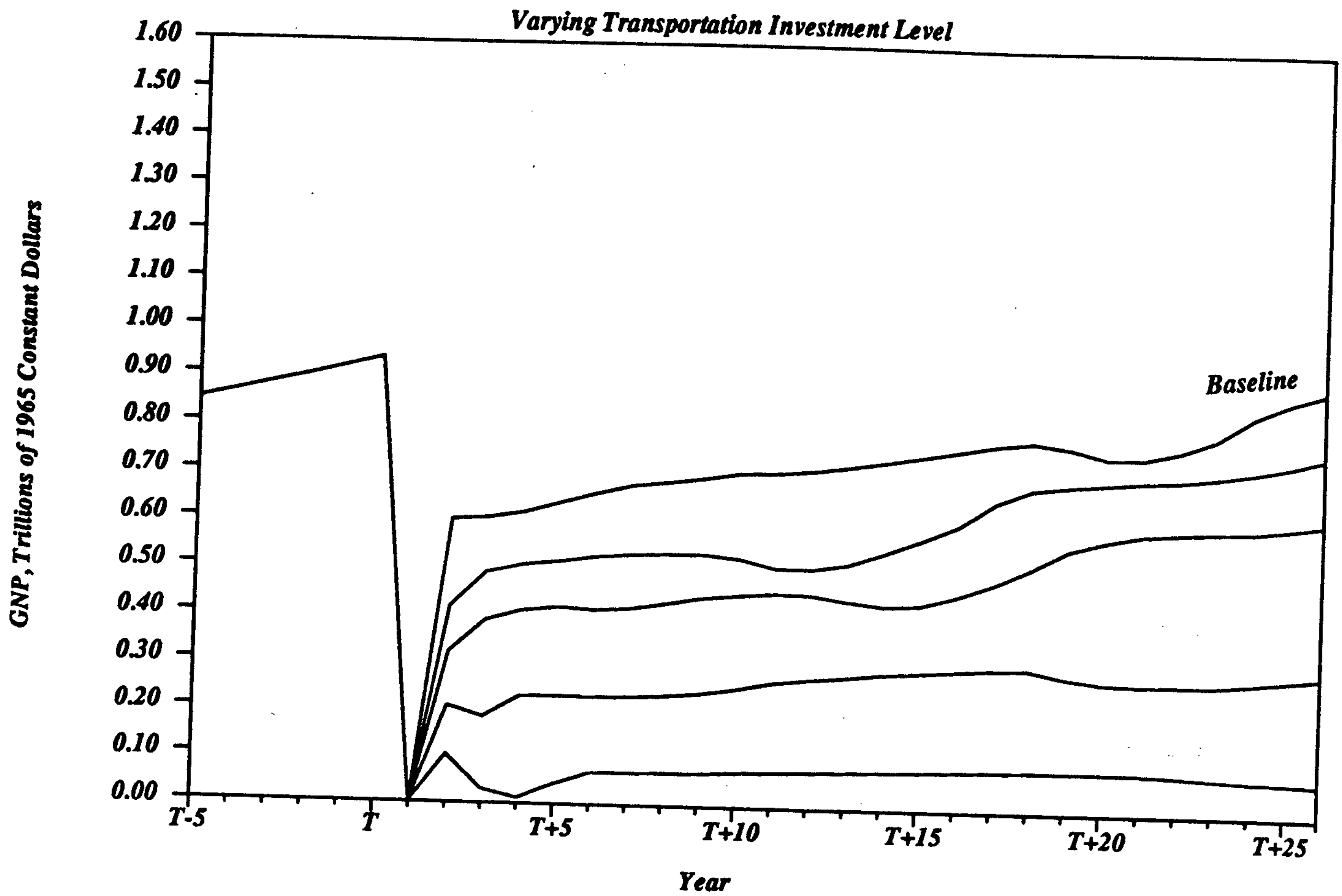
The question of how long it takes to reconnect unusable transportation capital is crucial because any initial lack of transportation can cause many other harmful effects, some of which could continue to influence economic performance for many years. For example, people would starve to death without adequate food transportation during that period. Other long-term effects could include capacity shortfalls, caused when the post-attack unavailability of transportation constricts capital expansion in all sectors. This effect is seriously damaging when the decline of capacity in the capital sector restricts the nation's ability to produce the capital required to build up more capital, a process essential for economic recovery.

The problem in determining the time it takes to reconnect transportation capital is that the aftermath of the attacks that we postulate are without historical precedent: Even in the smallest attack, virtually all of the petroleum refineries and the ports are destroyed, together with other energy facilities. As little as 5% of the nation's transportation capital might be usable immediately after the attack. Reconnecting the remaining transportation capital could be accomplished by 1) rebuilding refineries, 2) developing alternative fuel sources, and/or 3) developing alternate means of transportation. How long these energy intensive activities would take -- at a time when both fuel and transportation were limited -- is difficult to determine, and would depend on the policies implemented by the government. In order to allow us to test the effects of different policies, this time lag must be determined exogenously; that is, it must be determined by the modeler and imposed on the model.

There are two important time considerations -- how long does it take before transportation capacity equals the level of demand and how long does it take to bring transportation capital back to its pre-attack level. The first event would occur before the second because, after the attack, the damaged economy would initially be operating at a lower state and would not need the same amount of transportation capital.

The first of our tests showed the effects of neglecting to implement an investment policy favoring transportation (the lowest plot in the sensitivity tests graph labeled "varying transportation investment level").

SENSITIVITY TESTS



Baseline conditions (top)

Transportation bottleneck lasts a few months (next)

Transportation bottleneck lasts one year (middle)

Transportation bottleneck lasts a year and a half (next)

Transportation bottleneck lasts three years (bottom)

GNP hovers at around 10% of its pre-attack level for the entire duration of the simulation, showing no signs at all of recovery. Demand for transportation exceeds available transportation capital for three years; at this point, enough transportation has been reconnected and economic activity has fallen enough that there is an excess of capacity for the next two decades. Five years after the attack, half the disconnected capital is once again being used.

The second policy (the next highest curve on the graph) is one that reintegrates two-thirds of disconnected capital within two years of the attack. In spite of this, GNP stagnates at about a quarter of its pre-attack level for the entire two and a half decades after the attack. This policy is the one we use for our "baseline" scenarios, since it seems very unlikely that the rebuilt refineries could be created at a rate so that transportation requirements were fully satisfied in under two years. Under this policy, transportation general ceases to be a "bottleneck" in the economy in a year or a year and a half. Despite the fact that we considered this time lag for transportation capital reconnection to be the minimum we could justify, we tested policies that considered even shorter time lags. The middle curve on the graph shows a transportation re-investment policy which results in the transportation sector limiting the economy for only a year. The next higher curve has a policy that results in the transportation sector limiting the economy for only a few months. Of course, such short time lags are completely unrealistic in the aftermath of the nuclear attacks we consider, and yet they both result in levels of GNP lower than the baseline 40/40 attack (shown as the upper curve).

This behavior demonstrates two things. First, significant long-term damage can be caused by disruptions that occur in the first few months of the recovery attempt. Second, unbalanced attacks are much more devastating than balanced attacks, even when the unbalanced attacks are biased toward recovery with unrealistically optimistic assumptions.

For the remainder of this chapter we will return to the balanced 40/40 attack with no special targeting of petroleum.

4. Psychological Effects

A fourth key set of variables we explored in this test scenario were those representing psychological effects on the population and economy. The psychological effects variables intensify the effects on productivity of changes in various indicators, such as GNP. When the economy is recovering, this effect speeds the recovery process. When the economy is in a severe recession, even "mild" adverse psychological effects can be calamitous. Typically, psychological effects are strongly negative in the immediate aftermath of the attack but can recover to normal levels within a couple of years if the recovery appears to be proceeding. This is the case for the 40/40 scenario, but only if the psycholgical sector is operating at "mild" levels: at what we call "moderate" levels, the psychological influences are responsible for economic breakdown. Because of such effects as disillusionment with the leadership, people break away from traditional economic activity and the economy fragments into separate elements which no longer resemble the U.S. economy as we know it.

Quantifying Psychological Effects

The variable known as "public confidence" represents the most important psychological influences. It acts as a multiplier, which means that what is important is the relative change in its value from its normal level. The variable's normal value is one, although it can range from 0 to 2 in extreme eituations. Its value is determined by a combination of factors such as the standard of living and perceived improvement (of the economy and of the nation). If the standard of living is lower than its desired level (the desired level is, in turn, influenced by the trend of recent history of the actual standard of living), then people's expectations are not being met, and public confidence is lower. For example, if the actual standard of living is only half its desired level, under "mild" effects, public confidence falls by 20%. With "moderate" psychological effects, public confidence is halved.

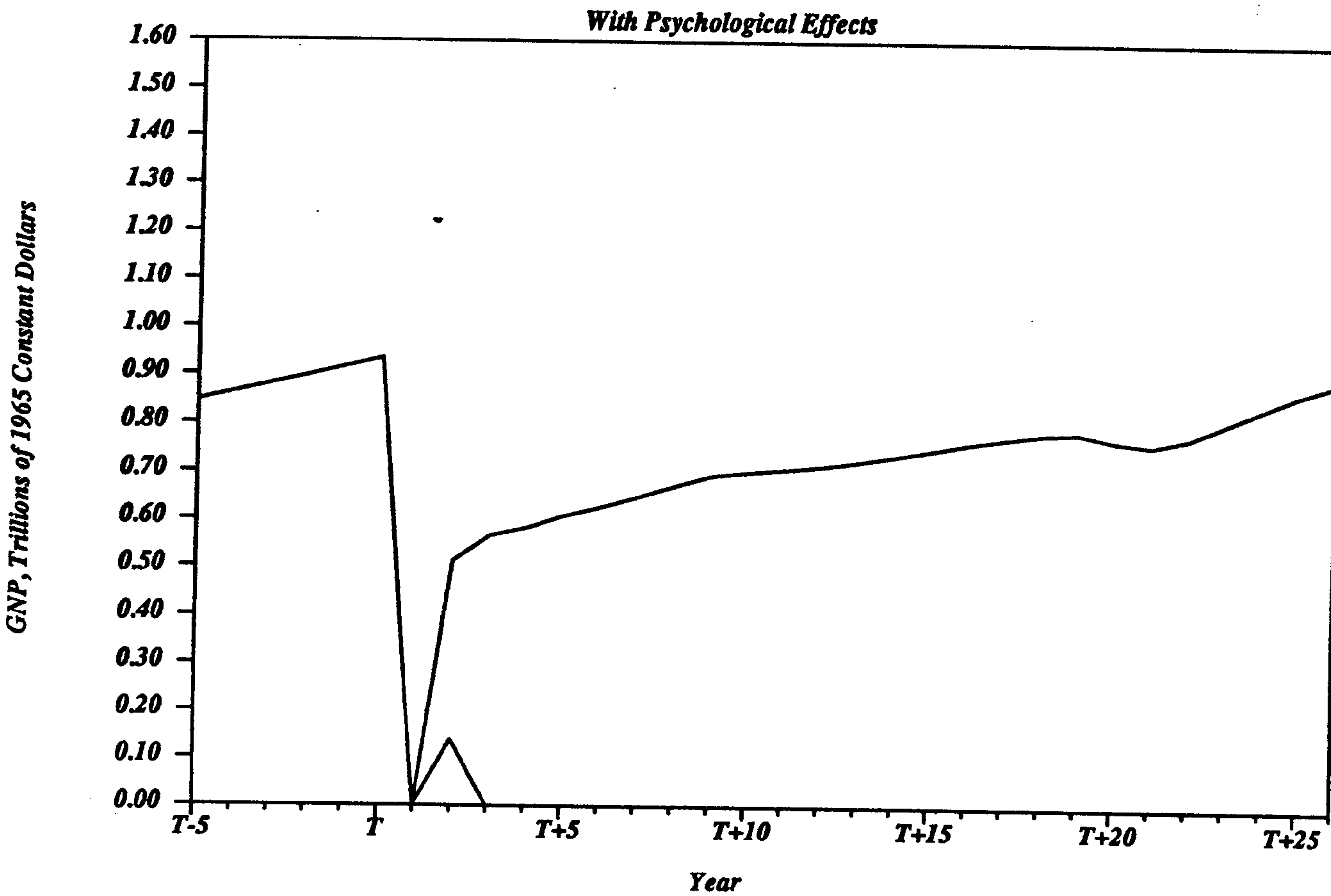
If GNP is perceived to be increasing at a rate of 25% per year, then mild effects would cause public confidence to grow 5% and moderate effects would result in a 20% growth in public confidence. These relationships are not linear: if GNP is changing at a large rate — say, falling 50% per year -- then mild effects call for a 10% drop in public confidence, whereas moderate effects show public confidence plunging by 60%.

The public confidence variable in turn influences others: if it is 25% higher than normal, productivity is increased by 5% in both mild and moderate cases; and if it is 25% lower than usual, productivity drops by 10% under either sets of effects. At the lowest end of the scale, however, moderate effects prove much more powerful: at public confidence levels one quarter of their normal level, productivity can fall to 45% of its usual level with moderate effects, compared to 60% for the mild conditions. Similarly, at a quarter of the normal level for public confidence, labor force participation can fall to half, if people exhibit moderate psychological effects; participation falls by only 25% if the reaction is mild.

The exact values of all these variables depend, of course, on the conditions depicted by the model at each instant in time. GNP recovers to values close to baseline levels within a few years of the attack when mild psychological effects are incorporated beacuse we are assuming that the population exhibits an extraordinary degree of resilience and also because the 40/40 scenario is balanced (per capita GNP does not change much, for example). In later scenarios, we find that the mild effects can have very negative influences. The moderate effects proved to be almost uniformly catastrophic.

This aspect of the model is one we tested extensively but have not included in the baseline attack scenarios because of the uncertainties involved in quantifying its influence. When either "mild" or "moderate" psychological influences are introduced in the baseline case (or any of the others mentioned above), the economy's performance worsens. This is especially true in the first decade following the attack, when GNP is at its lowest levels and the memory of the attack still fresh. In every case, the assumption of "moderate" psychological effects caused the economy to collapse; GNP plunges to zero within five years of the attack (as shown in the bottom curve of the sensitivity test graph labeled "psychological effects"). More informative were the results of incorporating "mild" psychological effects (as shown in the middle curve —

SENSITIVITY TESTS



Mild psychological effects (top)

Moderate psychological effects (bottom)

the baseline 40/40 is shown as the top curve for comparison). Any one of the factors we have just described, such as disconnecting transportation capital, tended to lower the level of GNP or cause it to fluctuate; adding psychological effects systematically tended to magnify such instabilities, causing even wilder fluctuations in GNP. This is because, as we have said, psychological effects help GNP grow whenever the economy is growing and it hurts GNP whenever the economy is declining.

Despite the fact that we did not rely on the inclusion of psychological effects in our baseline predictions of the results of various attack scenarios, we believe that the death, devastation, and deprivation that would follow any nuclear attack would probably have severely adverse affects on survivors for a long time. Therefore, we are including in the next chapter several tests that do incorporate psychological influences.

CHAPTER FIVE

RESULTS

In this chapter we will examine the predictions the FEMA model makes for the three baseline attack scenarios: the 60/40 attack (which corresponds to the standard counter-population and counter-industry scenario), the counter-energy attack, and the counter-energy attack augmented with a counter-industry component targeted at key economic sectors like primary metals manufacturing. To test the robustness of the results, we consider a variety of inputs to each of these scenarios.

THE 60/40 ATTACK

The 60/40 attack, described in Chapter One, postulates that the 71 largest U.S. cities are targeted with 500 weapons, each 550 kilotons in yield, and that an additional 200 to 300 smaller weapons, each 100 kilotons in yield, are targeted on industrial sites outside these cities. Such an attack, which totals about 390 equivalent megatons (or about 300 absolute megatons), would use about 6.5% of the Soviet Union's equivalent megatonnage (or 5% of their absolute megatonnage). The main 500-weapon attack kills three-quarters (and injures most of the rest) of the residents of the nation's largest cities. This amounts to a nationwide casualty rate of 60%.

Since industry also tends to be concentrated in urban areas, a total of 40% of the national manufacturing capacity is destroyed by this attack. The additional small-yield weapons destroy 97% of the U.S. production capacity in several industrial sectors that produce such crucial products such as drugs, refined petroleum, iron and steel works, nonferrous metals smelting and refining, engines and turbines, industrial machines, and electrical distrubution products.

Ports and airports would be devastated (and perhaps irradiated) by this attack, since many of the nation's ports and airports are located in the largest cities. In the months following the attack, there would be little opportunity to import anything. In particular, many of the facilities essential for importing liquid fuels would be destroyed, since most tanker terminals are located in or on the outskirts of major cities, or near refineries. Nevertheless, for the baseline attack scenario, during the first year we allow the economy to import all goods at 20% of their pre-attack rates (although we tested a spectrum of initial import rates), with higher rates in subsequent years: we allow this import level to double in about two years, and by the end of the first decade, imports are no longer restricted. This is a particularly optimistic assumption for commodities like petroleum that require special port facilities.

The loss of 97% of the petroleum-refining capacity following the 60/40 attack would reduce transportation-fuel availability to nearly zero. In the model, this is represented by disconnecting 95% of all transportation capital initially. The amount of transportation capital that is reconnected then grows in relation to the amount of investment available in the economy.

Since the 60/40 attack is directed at those industries most essential for maintaining economic activity, several of the model's eleven manufacturing sectors suffer disproportionately heavy losses. A total of 78% of the nation's metal manufacturing capacity is lost. The U.S. also loses half of its ability to produce capital equipment, energy, and utilities. Between 30% and 45% of the capacity in all other sectors is lost, with the exception of agriculture, which loses 3% (mainly its food-processing component). This attack is unbalanced, disproportionately damaging liquid fuels and metals -- key sectors in any reconstruction effort.

We timed this 60/40 attack for 1981 (year T in the graphs), and the model predicted the effects on the economy until 2006, although in several cases we extended the duration of the simulation to 2020. The first graph (Graph A) shows the behavior of GNP following the 60/40 attack under very optimistic conditions: immediately after the attack, the import availability for all goods, including petroleum, stands at 20% of the pre-attack level (availabilities climb by about 10% of the pre-attack level in each subsequent year). In the transportation sector, capacity exceeds demand within one and a half years of the attack, and no psychological effects are included.

The model shows that the economy collapses within a few years of this attack. The U.S. economy may not function again as a nationally integrated, interdependent economy for many decades to follow. The deterioration of economic activity is caused by the combination of many factors, including, initially, the millions of injured people, the lack of liquid fuel availability, and the severe imbalances caused by selectively targeting crucial industries.

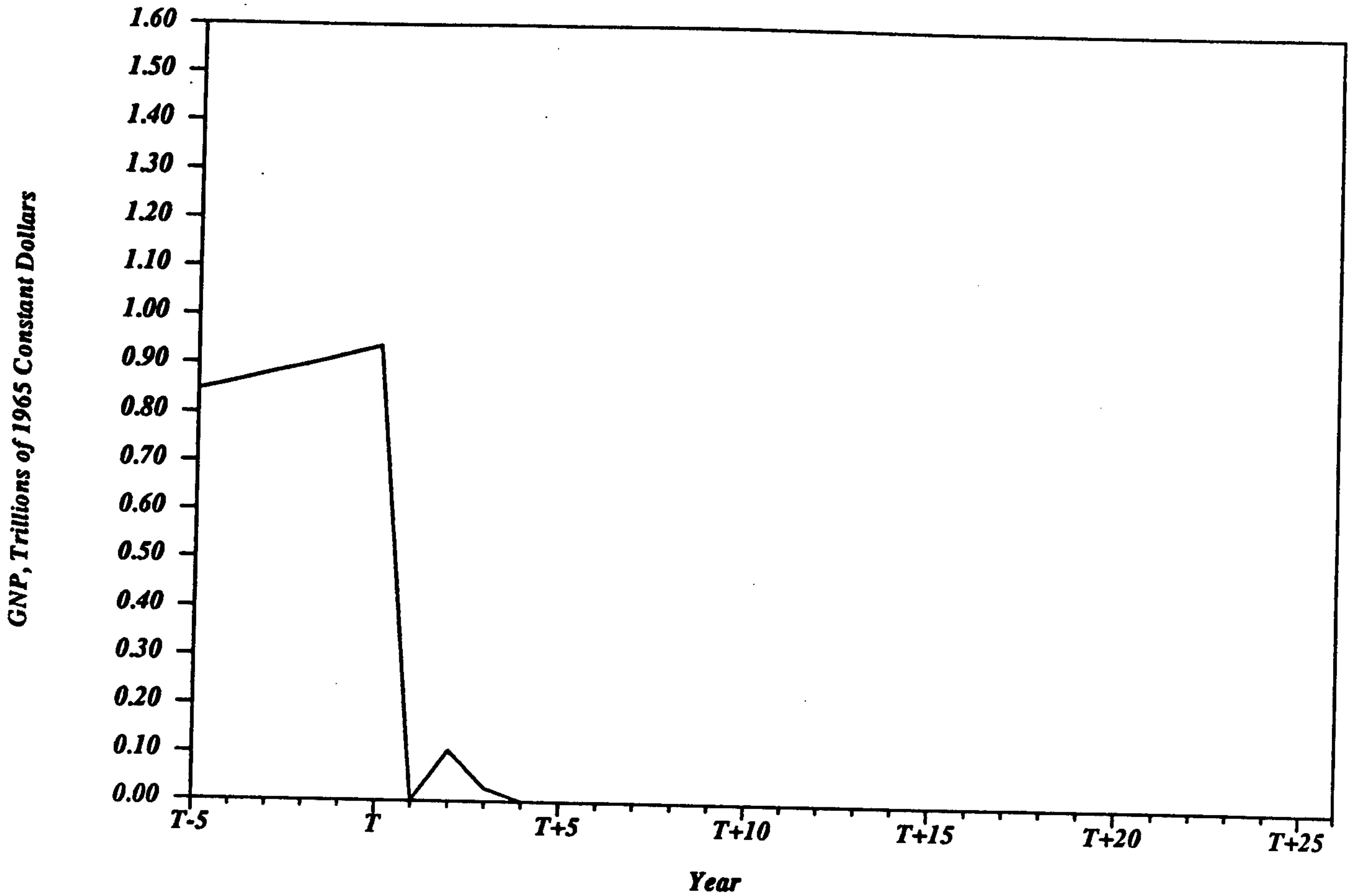
It is difficult to find realistic inputs that can cause the FEMA model to show recovery following the 60/40 attack. Although we have argued that assuming 20% import availability immediately after the attack is optimistic, much large levels of imports do not stave off collapse. Moreover, the results in Graph A were calculated assuming that the psychological effects sector of the model was turned off. Yet, we believe that after such a large attack people would have at least some psychological reaction, ranging from the depression, apathy and lethargy exhibited by the survivors of Hiroshima to complete withdrawal from the national economy. The incorporation of mild psycholgical effects into the 60/40 attack only serves to accelerate the economic crash.

The results of these simulations suggest that the 60/40 attack is significantly larger than the minimum required to cause the collapse of the economy. Our subsequent tests suggest that fewer than one-third the number of weapons that cause the devastation of the 60/40 attack can inflict economic damage of almost equally catastrophic proportions. We turn now to an analysis of the possible effects of such an attack.

THE COUNTER-ENERGY ATTACK

The counter-energy attack consists of 85 550-kiloton weapons and 154 200-kiloton weapons, a total of 239 nuclear weapons that add up to 110 equivalent megatons — under 2% of the deployed equivalent megatonnage of the Soviet Union. In absolute megatons the attack is even smaller, under 1% of the total Soviet megatons. Appendix Two gives the complete target

GRAPH A



60/40 Attack

list for this attack.

The attack is designed to inflict the maximum economic damage while minimizing the attack size; to do this, only the facilities that refine, store and transport liquid fuels are targeted. Although urban areas are not deliberately targeted in this scenario, most of the major U.S. cities end up receiving one or more weapons. This is a by-product of the targeting strategy, which blasts every commercial dock and berth capable of bringing imports into the nation with at least 5 psi [1]. Other explicitly targeted facilities include the nations's Strategic Petroleum Reserve, maintained at five Texas and Louisiana sites by the Department of Energy as a protection against a sudden drop of liquid-fuel availability [2]. Over 95% of all operating U.S. refineries [3] are destroyed by this attack, which also obliterates almost every inactive refinery. The attack targets the major nodes -- junctions of over five lines, terminals, and pump or compressor stations -- of the nation's three pipeline systems, which are used to transport crude petroleum, petroleum products, and natural gas [4]. Although industrial installations are not selected as targets, the attack also destroys 25% of the nation's primary steel manufacturing capacity and 18% of primary nonferrous-metals manufacturing (many metals-producing plants tend to be located near port and refinery facilities). In all, the U.S. loses 33% of its capacity to produce energy products, 19% of its capacity to make metals, and between 5% and 10% of its capacity to manufacture other products; overall, the U.S. economy loses 8% of its manufacturing capacity. About twenty million Americans die immediately following this attack, which also injures five million: casualties total 10%.

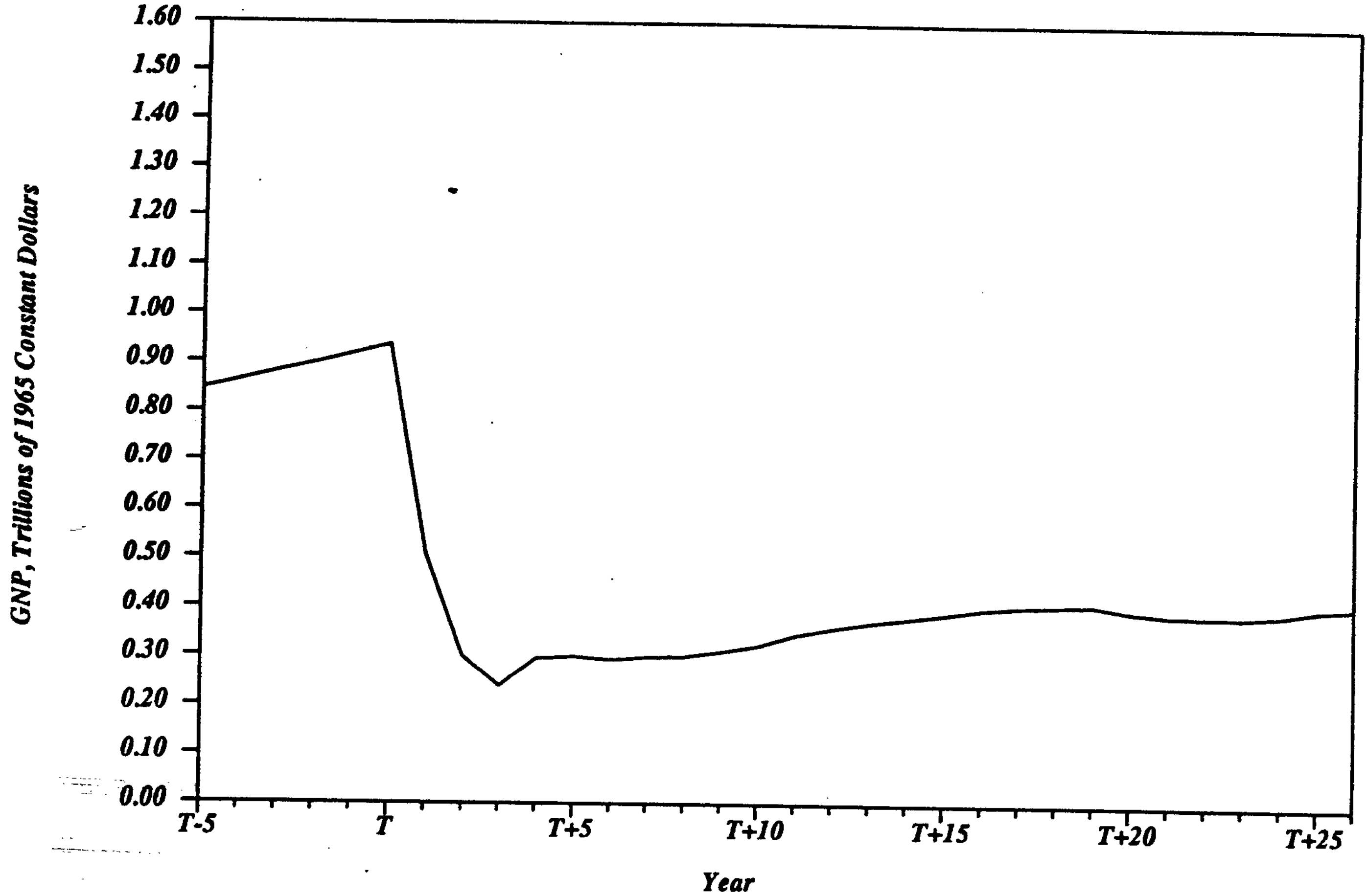
This is a very small attack compared to the 60/40 attack (which had 60% immediate casualties and 40% immediate destruction of the nation's manufacturing capacity). Considering that the direct casualties are about 10% of the population, and that the attack directly destroys only about 8% of the nation's manufacturing capacity, this attack could be called the 10/8 attack.

Despite our consistent use of conservative assumptions to estimate damage and casualty rates, the model simulations indicate that the consequences of the counter-energy attack would be severe (see Appendix I, where we present a representative set of the graphical output and a discussion of its interpretation). In a scenario that optimistically allows 10% of the pre-attack rate of energy imports and 20% of the pre-attack rate of all other imports to arrive in the U.S. immediately after the attack (with much higher levels in subsequent years — for instance, energy imports double in about one year), includes no psychological effects, and posits that transportation capacity equals demand about one year after the attack, the economy is devastated, as plotted in Graph B.

As expected, it is the lack of transportation adequacy that is responsible for the initial plunge in GNP (see Appendix I). The attack destroys only 8% of the nation's manufacturing capacity, but GNP falls by over 50% in the first year after the attack.

Available transportation capital falls immediately to about 5% of its pre-attack level. Yet the assumption that transportation capacity equals demand about one year after the attack means in some sense that transportation is no longer a "bottleneck" to recovery one year after the attack. The policy of investment in energy and transportation we have

GRAPH B



Counter-Energy Attack

Baseline Conditions

assumed here brings transportation capacity to 50% of its pre-attack level in about one and a half to two years of the attack and brings transporation capacity to near its pre-attack level about three years after the attack. Yet even with these exceedingly optimistic assumptions, the lack of transportation in the early months continues to influence the nation's capacity to produce for decades; for if in these early years people starve and stocks of vital supplies are exhausted, it can take many, many years to undo the harmful effects.

About 8% of the population is killed directly by weapons effects, but almost 60% die within two years of the attack. People starve to death without food, which cannot be transported from the middle of the country where it is produced to the large urban centers on the two coasts, and factories cannot produce goods without materials and labor.

The mass starvation that takes place after this attack (and other attacks) should be considered a qualitative feature of the model. It seems likely to us that the highest priority for the many people in the post-attack world would be survival, rather than rebuilding the U.S. economy. In this case, it is very possible that the U.S. economy would be transformed dramatically after a nuclear attack, perhaps becoming far more agrarian; mass migration to areas near the crop lands of the Mid-West might occur. This would allow the land to be cultivated using labor-intensive techniques that do not rely on fossil fuels and machinery. In this way, mass starvation would be avoided. On the other hand, if this occurred, GNP would stabilize at much lower levels than Graph B indicates, and recovery of the GNP to pre-attack levels could take several decades [6].

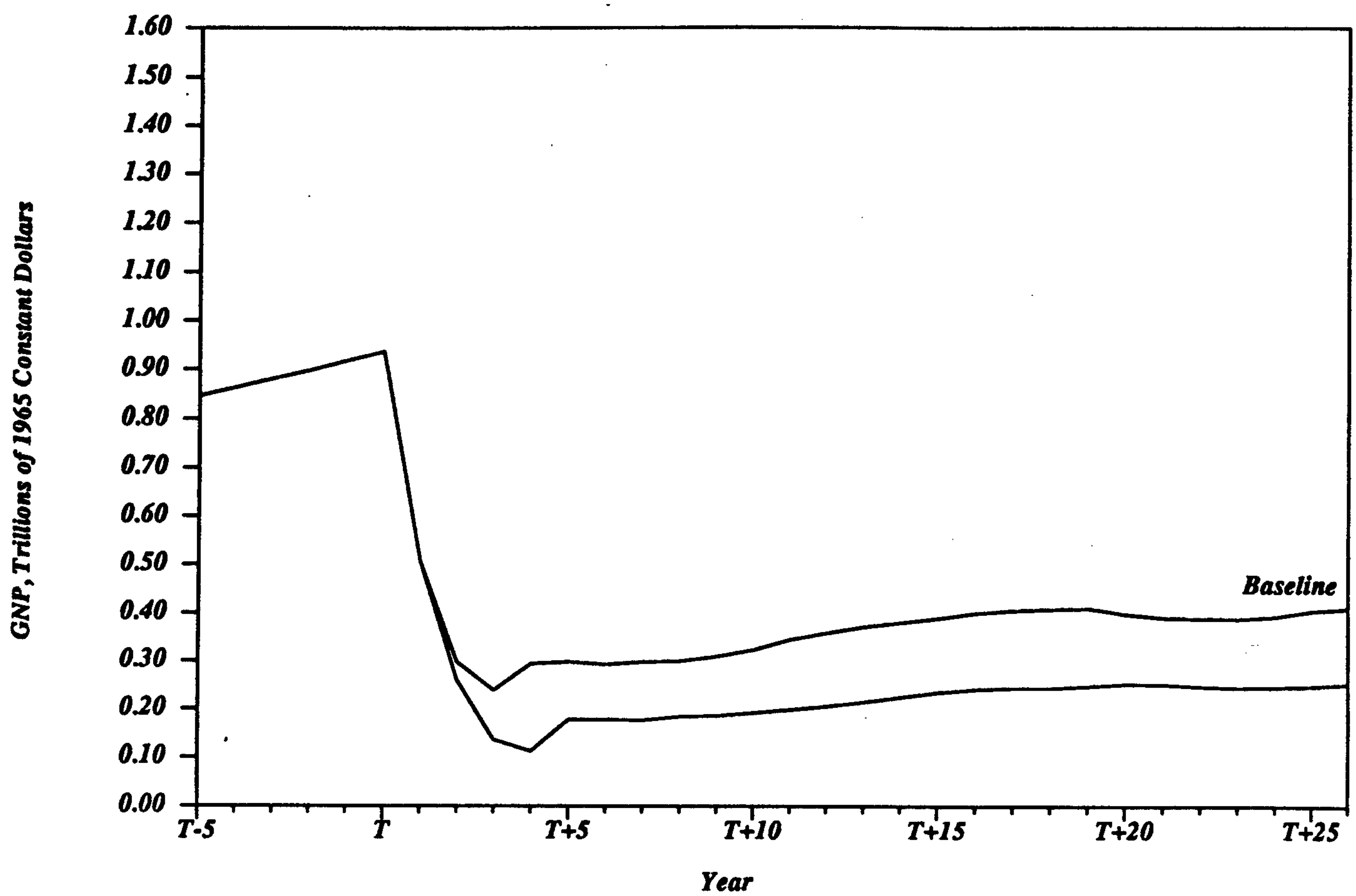
To represent people removing themselves from the workforce for any reason (to insure their survival or their family's survival or just because of the psychological shock of the attack), we might include mild psychological effects in the counter-energy attack. The result, indicated in Graph C, shows the economy languishing at about a quarter of its pre-atack level for 20 years. It bears repeating that mild psychological effects are rather mild: if the GNP is falling at a rate of 50% per year, the main effect on the economy is that worker productivity falls by a few percent.

Moderate psychological effects have an even more devastating effect on the economy, causing complete economic collapse within three years of the attack, as shown in Graph D.

Until the end of the discussion of the counter-energy attack, we will turn off the psychological effects sector of the FEMA model and consider that there is no adverse psychological reaction to the attack. This optimistic assumption will allow us to examine independently the effects of changing the values of other inputs to the model.

Although we consider the level of imports we allot for this attack to be optimistic, we also examine even higher levels of imports. First, we test the original import rates -- 10% fuel, 20% other goods — augmented by doubling the import availability of food to 40% in just the first year after the attack (as before, these levels are relative to the pre-attack import rates and they are incremented every subsequent year). The results are shown in Graph E. GNP is consistently about 15% higher. Fewer people starve, and the economy consequently can perform better. When all imports are doubled, to a rate of 20% for fuel and 40% for other goods, again

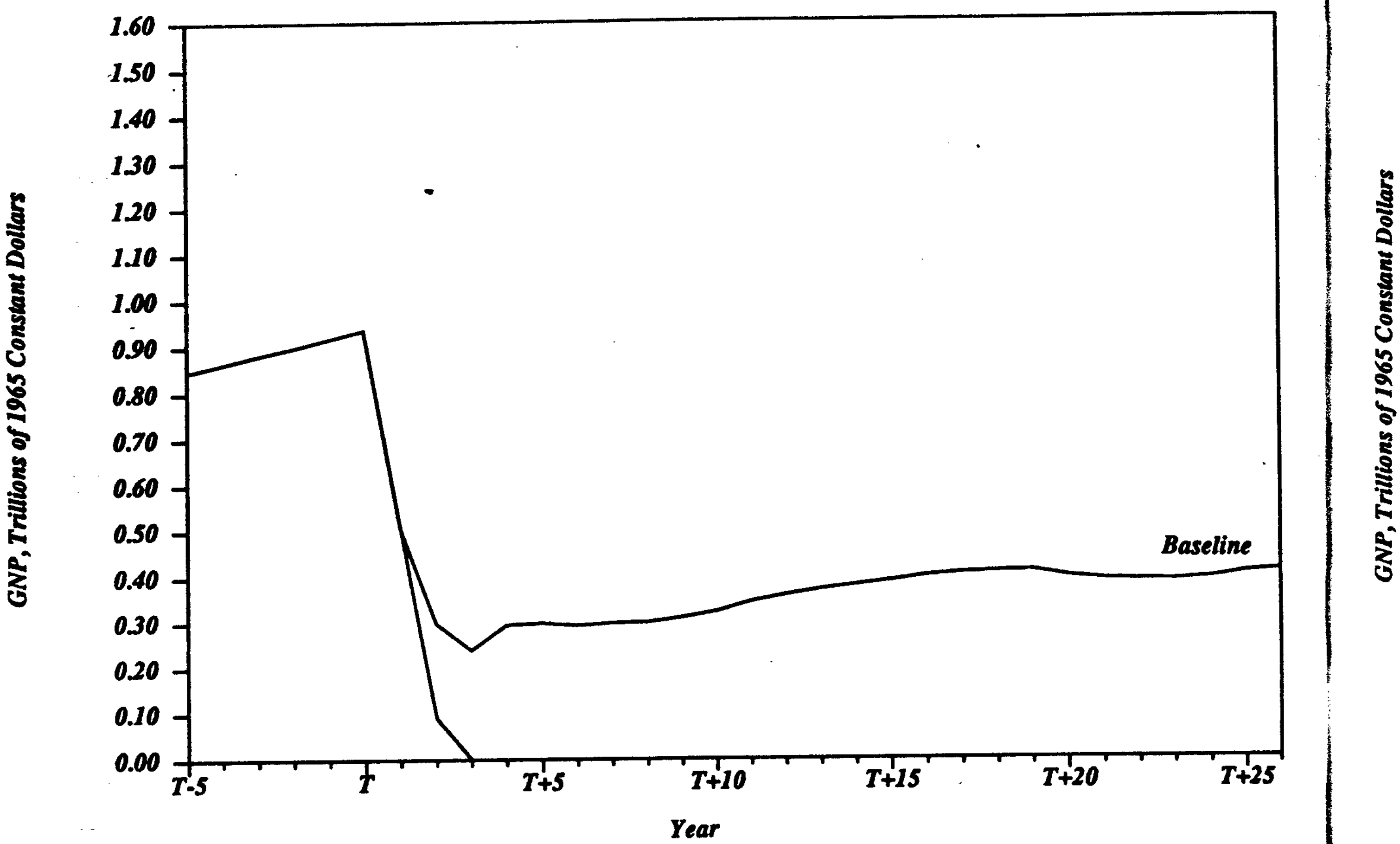
GRAPH C



Counter-Energy Attack

mild psychological effects

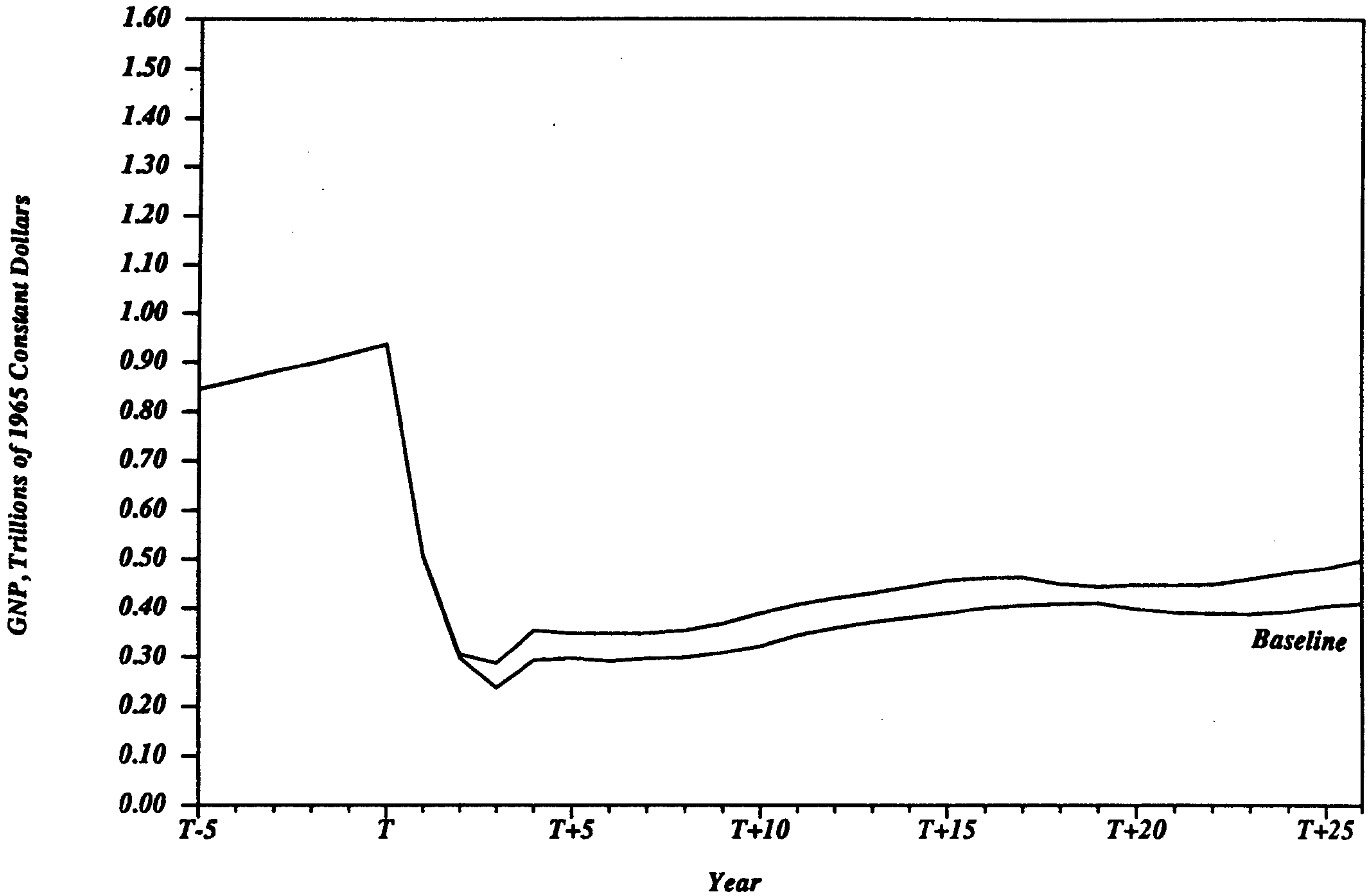
GRAPH D



Counter-Energy Attack

moderate psychological effects

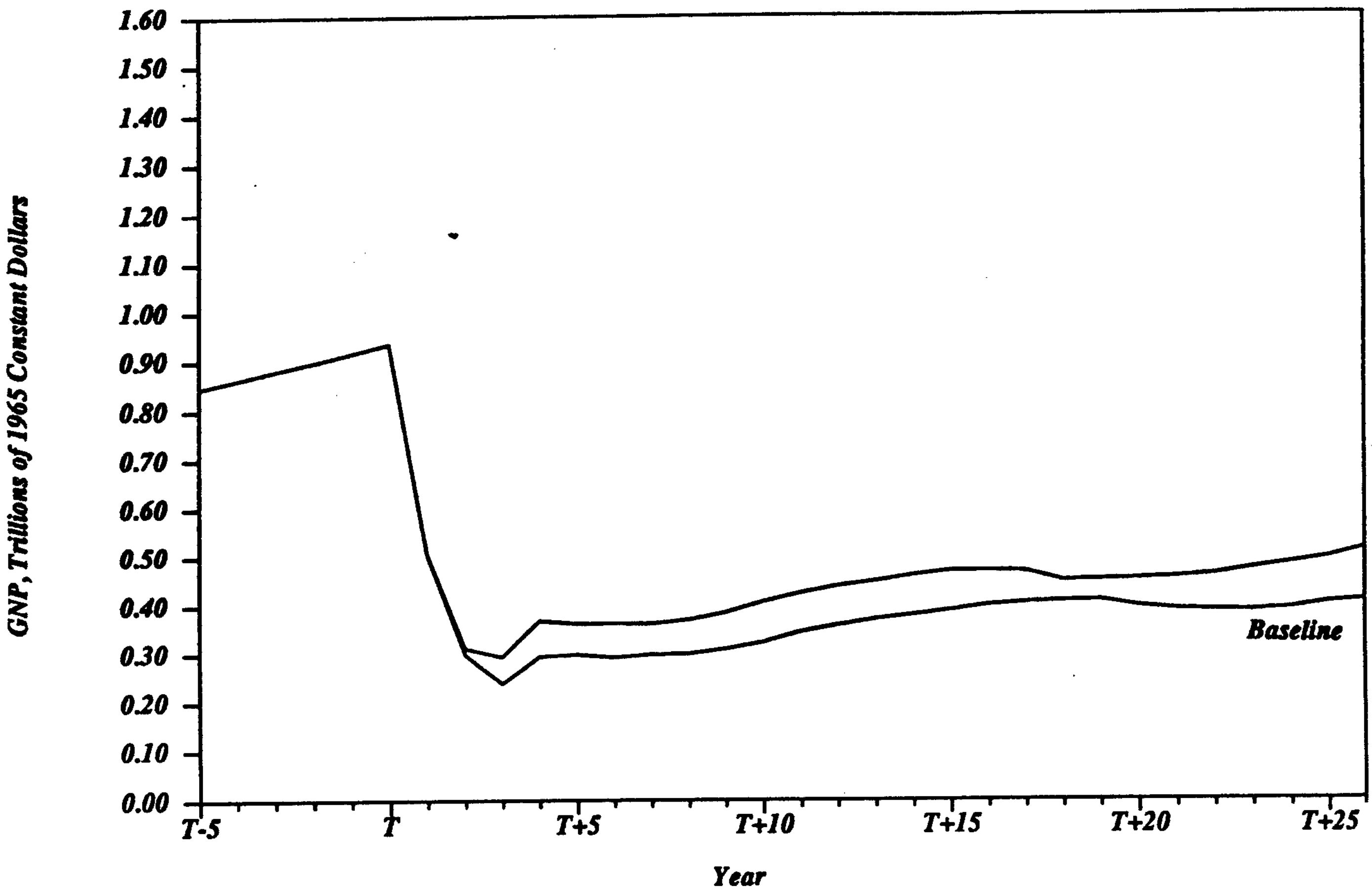
GRAPH E



Counter-Energy Attack

food imports doubled

GRAPH F



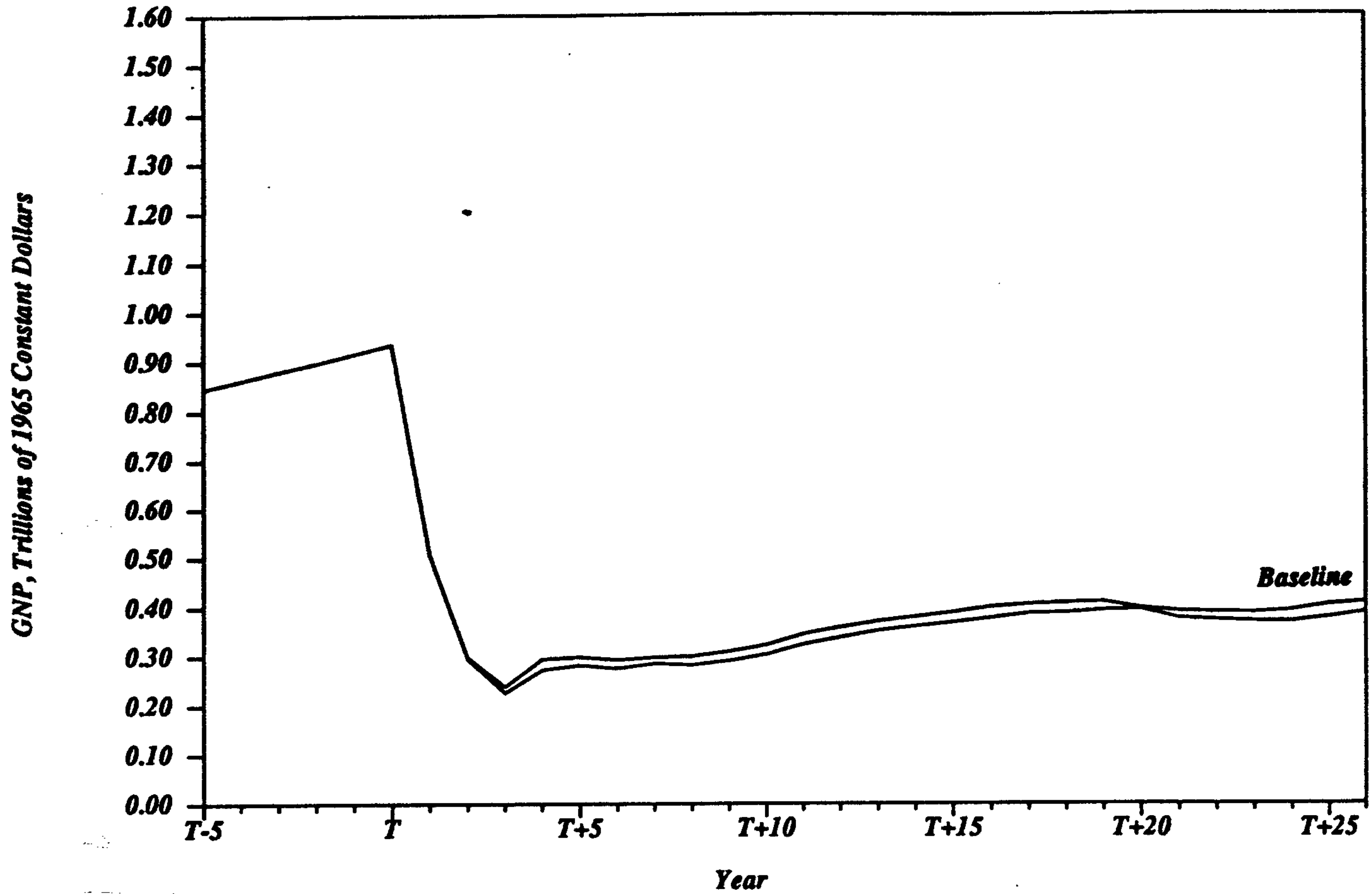
Counter-Energy Attack

all imports doubled

with higher levels in subsequent years, GNP follows a similar path (see Graph F), indicating that it is the food imports that are important. Even higher rates of imports were tested, and while they tended to improve the economy somewhat in the short term, they were not so beneficial in the long term, insofar as they induced the economy to depend on imports, rather than rebuild its own manufacturing base. This is perhaps not surprising, in the light of the events of the past several years. [7].

The conditions represented in the two preceding test runs are probably unrealistically optimistic. Every commercial port that can be used to import significant quantities of goods and materials was destroyed in the counter-energy attack scenario, after all, and every major city targeted. States that had in the past done a great deal of importing would be struggling just to save survivors; as listed in Appendix II, in this attack, for instace, California gets 21 weapons, Louisiana gets 23, Texas gets 38, and Florida gets 13. Moreover, it is far from clear that other countries will be in a position to help us for they may be struggling in a global depression following the crash of the U.S. economy, or they may be directly targeted (as seems very possible in the case of Canada or Mexico [8]). At the very least, food imports will be very hard to come by after the U.S. stops exporting mass quantities and starts importing. More likely conditions would probably be import rates lower than our baseline rates, with energy imports initially reduced to a trickle, say, 5%. If we permit 15% of all other imports to be brought into the nation, we find that lowering import availability after the counter-energy attack reduces GNP performance only slightly, as shown in Graph G.

GRAPH G



Counter-Energy Attack

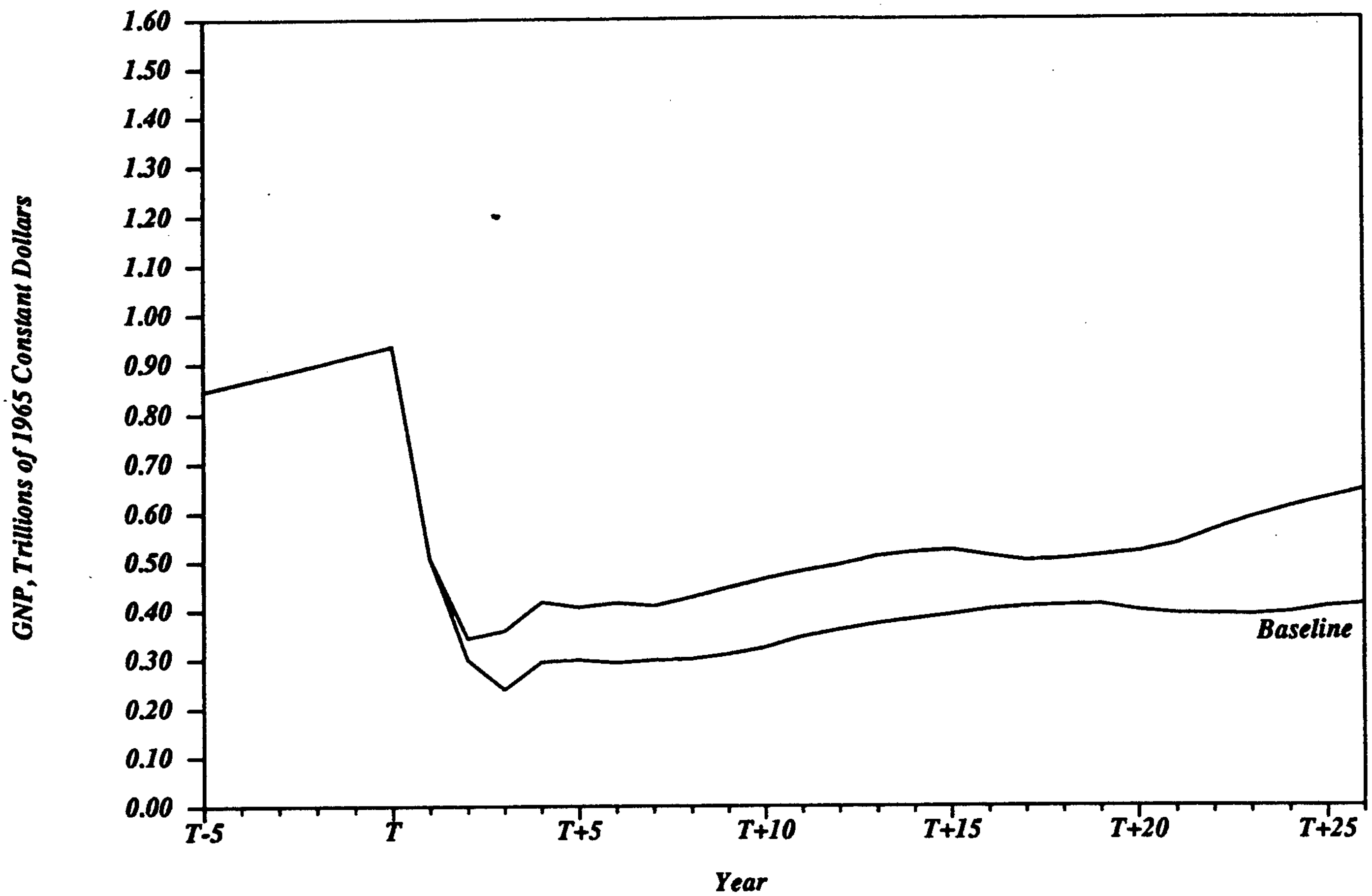
all imports reduced

The transportation reconnection rate turns out to be an important determinant of the recovery rate. Although we consider our baseline conditions optimistic, we consider a policy which results in transporation capacity exceeding demand within months of the attack and has the vast majority of transportation capital returning within two years of the attack. As Graph H shows, GNP is higher and recovery is faster, yet even in this very optimistic case, where the transporation bottleneck lasts less than a year, the economy is devastated and large instabilities threaten recovery.

In Graph I we show the effect of a slower reconnection rate. Here, the prespects for any kind of recovery at all appear bleak. In this case, it takes two years for half of the transporation capital to be reintegrated, at about which time capacity exceeds demand and transportation is no longer a bottleneck to recovery. For many reasons, we believe these assumptions are far more realistic than our baseline conditions.

For instance, an extremely optimistic feature of the model is its assumption that scarce resources are allocated in ways that are optimal to recovery. After a real nuclear war, however, it seems much more likely that scarce resources would be allocated haphazardly (or that the military might simply appropriate them). Therefore, all of the results presented here are already biased towards predictions of recovery in situations that in reality could cause the immediate downward plunge of GNP characteristic of complete collapse. Yet our simulations that show GNP stagnating at levels a small fraction of pre-attack GNP cannot be considered recovery; indeed, one of the few things we can be fairly confident about in such

GRAPH H

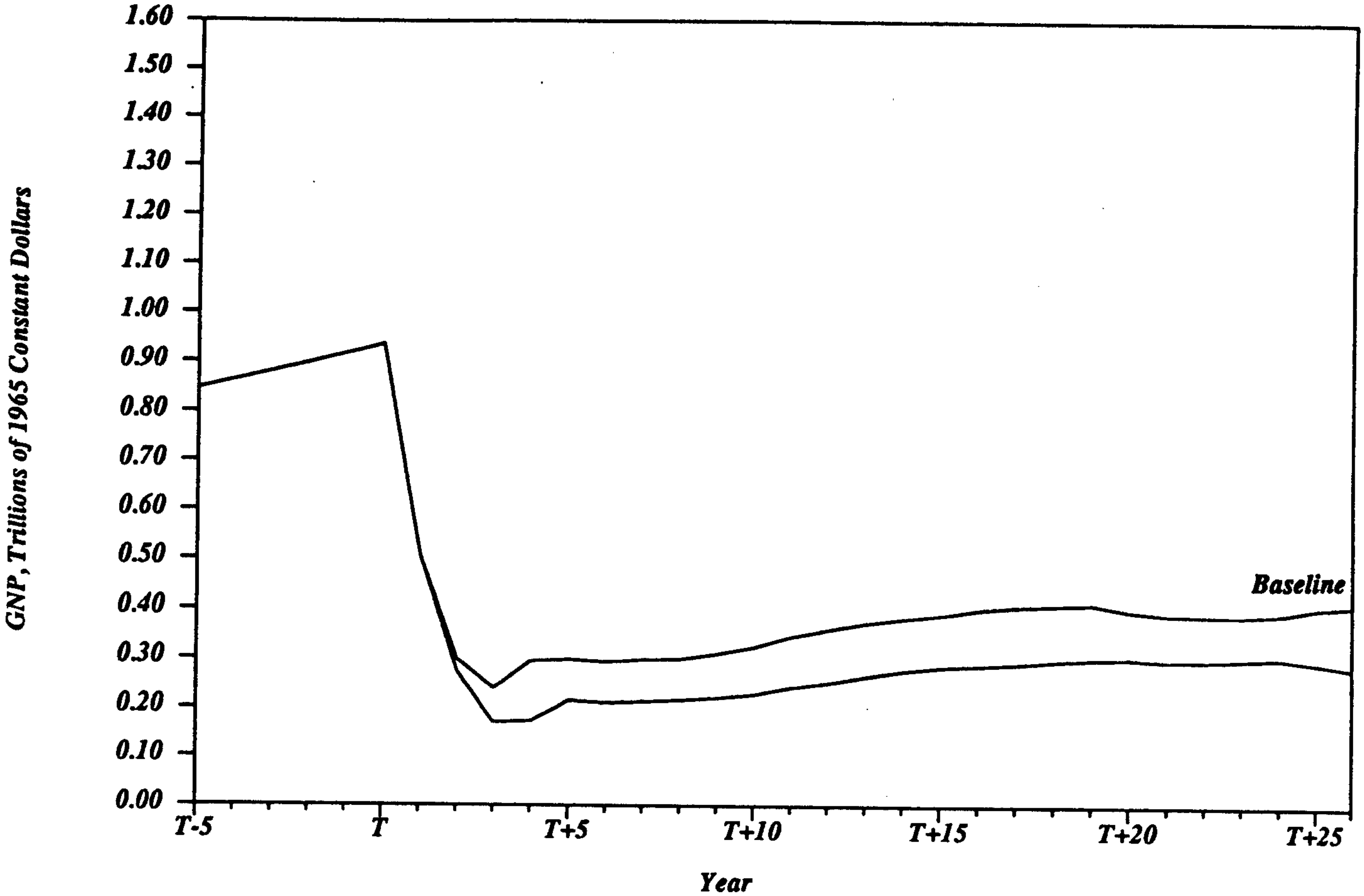


GNP, Trillions of 1965 Constant Dollars

Counter-Energy Attack

faster rate of transportation reconnection

GRAPH I



Counter-Energy Attack

slower rate of transportation reconnection cases is that the economy is not recovering.

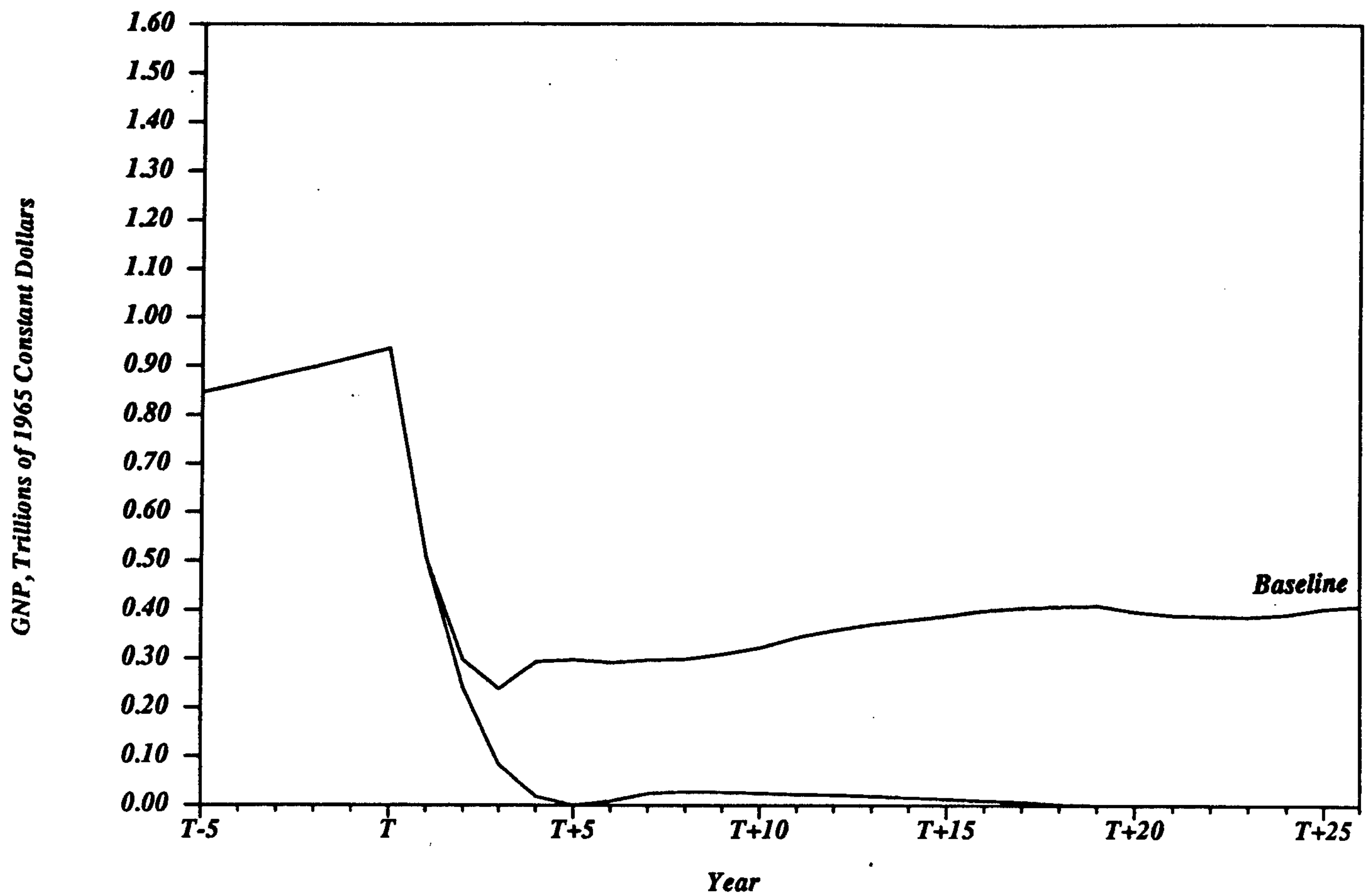
As we have said, our baseline conditions combine several assumptions we believe to be optimistic. If we made just two of those assumptions more realistic — adding mild psychological effects to the slower reconnection rate for transportation -- the counter-energy attack collapses the economy, as shown in Graph J. As before, transportation capacity exceeds demand within two years, yet by this time the population has dwindled and incentives to increase the recovery simply do not work: the survivors are discouraged. In the second post-attack decade, as the anticipated recovery fails to materialize, public confidence plunges further and workers begin to withdraw from the organized economy, possibly to take part in fractionalized, low-level forms of economic activity. It is this migration that finally causes the complete collapse of the U.S. economy.

This is perhaps the most realistic path for the economy after the counter-energy attack.

THE COUNTER-ENERGY, COUNTER-INDUSTRY ATTACK

In this attack scenario, the counter-energy attack was augmented by adding several dozen weapons, 30 550-kiloton bombs, and 62 200-kiloton bombs. The targets of these weapons were the largest installations in several key manufacturing industries. Six industries were chosen for their importance in the economy and because they are geographically concentrated. Blast furnaces and primary nonferrous-metals manufacturing, two components of the metals-producing sector, are essential for the

GRAPH J



Counter-Energy Attack

slower rate of transportation reconnection
with mild psychological effects

manufacture of all metals in the U.S. Each of these industries loses over 80% of its production capacity in this attack scenario. Four other industries suffer between 50% and 60% destruction. They are: motors and generators; engines and turbines; ball- and roller-bearings; and semiconductor manufacturing. The products of these sectors would be of crucial importance in the post-attack recovery effort. There would be an enormous demand for semiconductors following the effects of the electromagnetic pulse (EMP) during the attack; as we described in Chapter One, a single high-altitude nuclear detonation can severely damage electronic components nationwide. Semiconductors, the vital components of computers, can break down irreparably due to EMP, impairing all communication and information-storage systems.

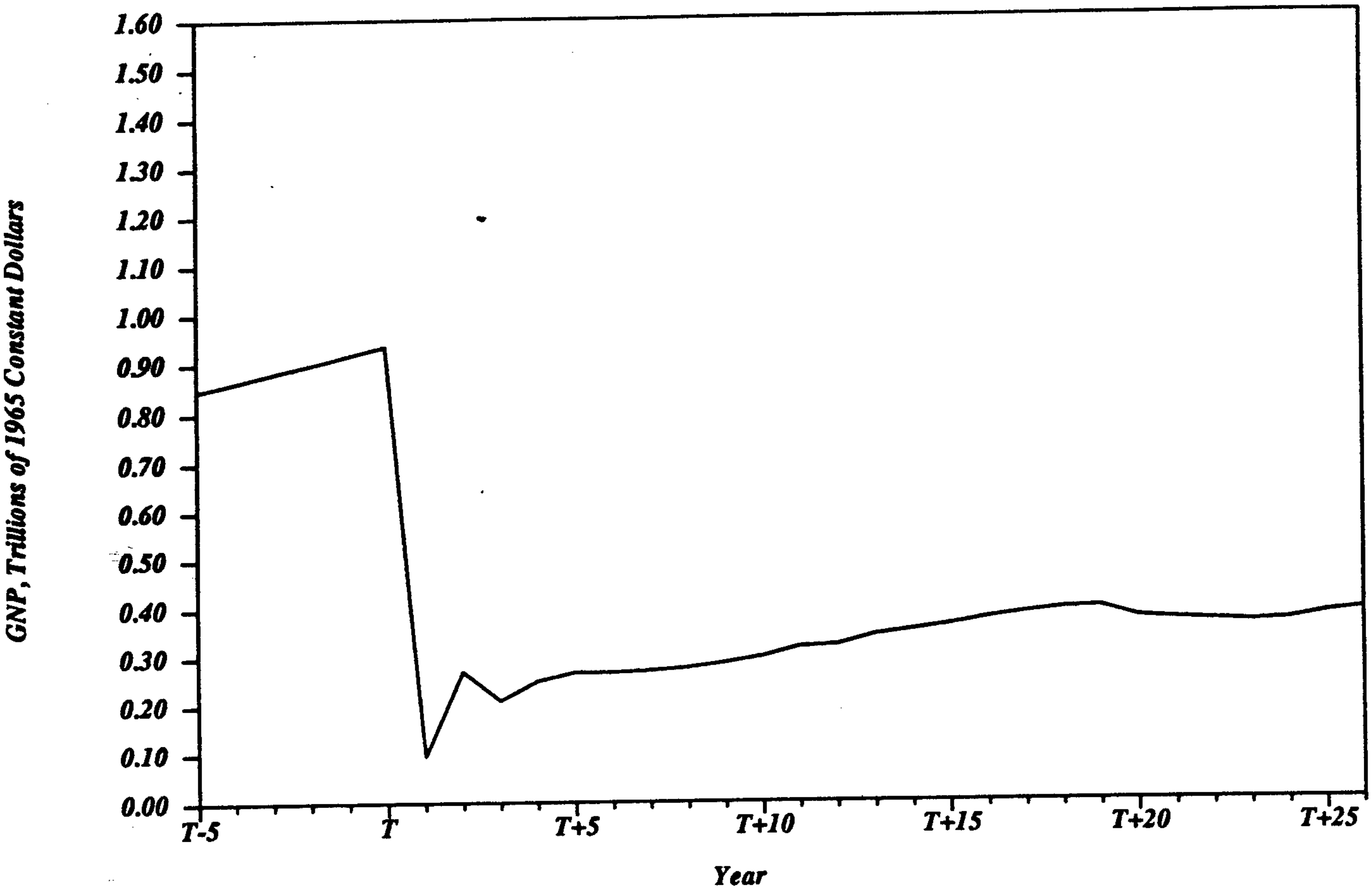
The counter-energy, counter-industry attack is still relatively small in size -- much smaller than the 60/40 attack, for instance. It totals 150 equivalent megatons -- equal to just over 2% of the Soviets' total megatonnage. The attack kills nearly 12% of the total population, 29 million, and injures 3%, or 7 million. The nation's urban areas suffer the brunt of this attack, which directly affects a total of 50 million inhabitants living in the cities, suburbs and towns that receive at least one weapon each. The majority of weapons fall on those states that contain the highest concentration of industry, which also happen to be among the most heavily populated and contain the larger share of the nation's academic, educational, and cultural institutions.

In this attack, the economy suffers 16% overall destruction. And so this attack should be considered a 15/16 attack (in contrast to the 60/40 Katz attack or the 10/8 counter-energy attack).

The primary metals and energy-products sectors lose 76% and 34% of their capacity respectively; most other sectors lose between 10% and 20% of their production capacity. It is important to recall that because of the structure of aggregate sectors in the programs we used, the model cannot reflect the complete extent to which this attack would damage the economy, since it cannot separate out the particular industries attacked. In particular, the capital-equipment sector of the model includes many products other than motors, generators, engines and turbines. While these key industries lose over 50% of their capacity, compared to the much lower level of destruction (under 15%) suffered by other, untargeted industries, the model depicts the effects of this attack as a 17% overall reduction of the capital-producing sector. Thus the model's results actually indicate the effects of a much more balanced attack, rather than the extreme one we have described. We therefore expect the test runs for this scenario to underestimate severely the effects of the counter-energy, counter-industry attack. As usual, the actual conditions would be much worse. Even with this unavoidably optimistic aggregation of industries, the FEMA model indicates that this attack has a severe effect on the economy.

Graph K indicates the prediction the FEMA model makes for GNP following the counter-energy, counter-industry attack. The same optimistic assumptions used in the baseline counter-energy attack are used here: no psychological effects are taken into account (although following this larger attack, adverse psychological responses would be all the more likely to reach proportions that would influence economic behavior), the same time lags for reconnection of transportation capital are used, and the same post-attack import rates are used.

GRAPH K



Counter-Energy, Counter-Industry Attack

baseline conditions

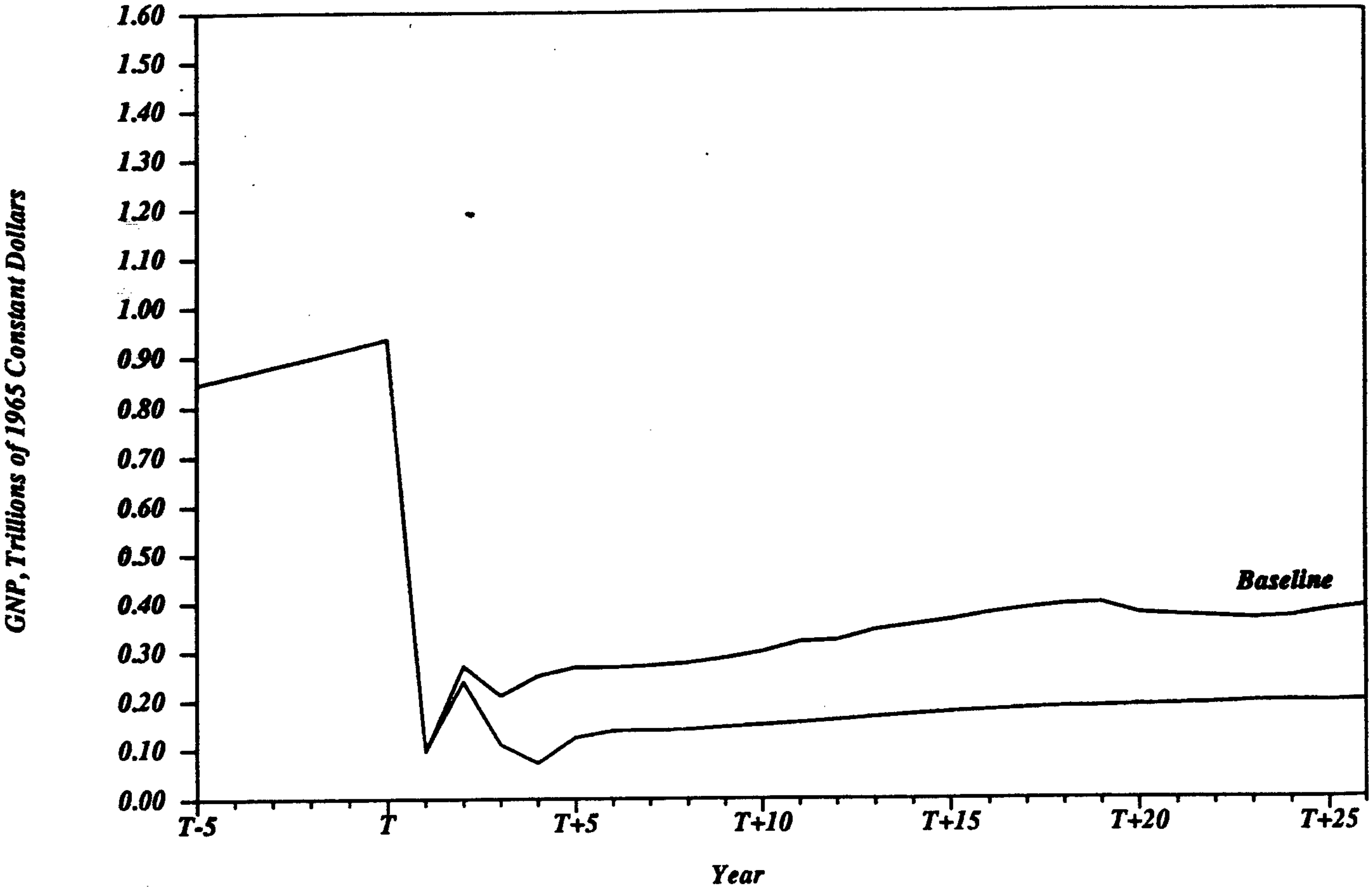
This graph is quite similar to the baseline counter-energy attack of Graph B. The main difference between these two graphs occurs right after the attack, where Graph K indicates greater economic instability in the first few years after the attack. This is not surprising, given the extra damage to several industrial sectors that would be crucial to reconstruction.

Nevertheless, in the long run, the counter-energy, counter-industry attack is quite similar to the counter-energy attack. Therefore, we will not repeat all the graphs in the previous section that had even more optimistic initial assumptions. They are very similar for both attacks.

Moreover, following this larger attack, we would expect much worse conditions. Many of the industries destroyed in this attack would be crucial for rebuilding refineries, transportation capital, and ports. Therefore, it seems prudent to consider inputs for this attack that are
25 less optimistic than the ones used in the counter-energy attack.

Because of the greater number of casualties in this attack, and the large number of shortages in key industrial products that would occur in the years after this attack, it seems likely that the survivors would suffer at least some adverse psychological reaction. If even mild psychological effects are incorporated in the counter-energy, counter-industry attack, then, as indicated in Graph L, the economy performs much worse, languishing at about 20% of its pre-attack level for 25 years, with no sign of significant recovery. For the remaining graphs considered in this section, we will turn off the psychological effects sector of the FEMA model and consider, optimistically, attacks that have no adverse psychological effects.

GRAPH L



Counter-Energy, Counter-Industry Attack

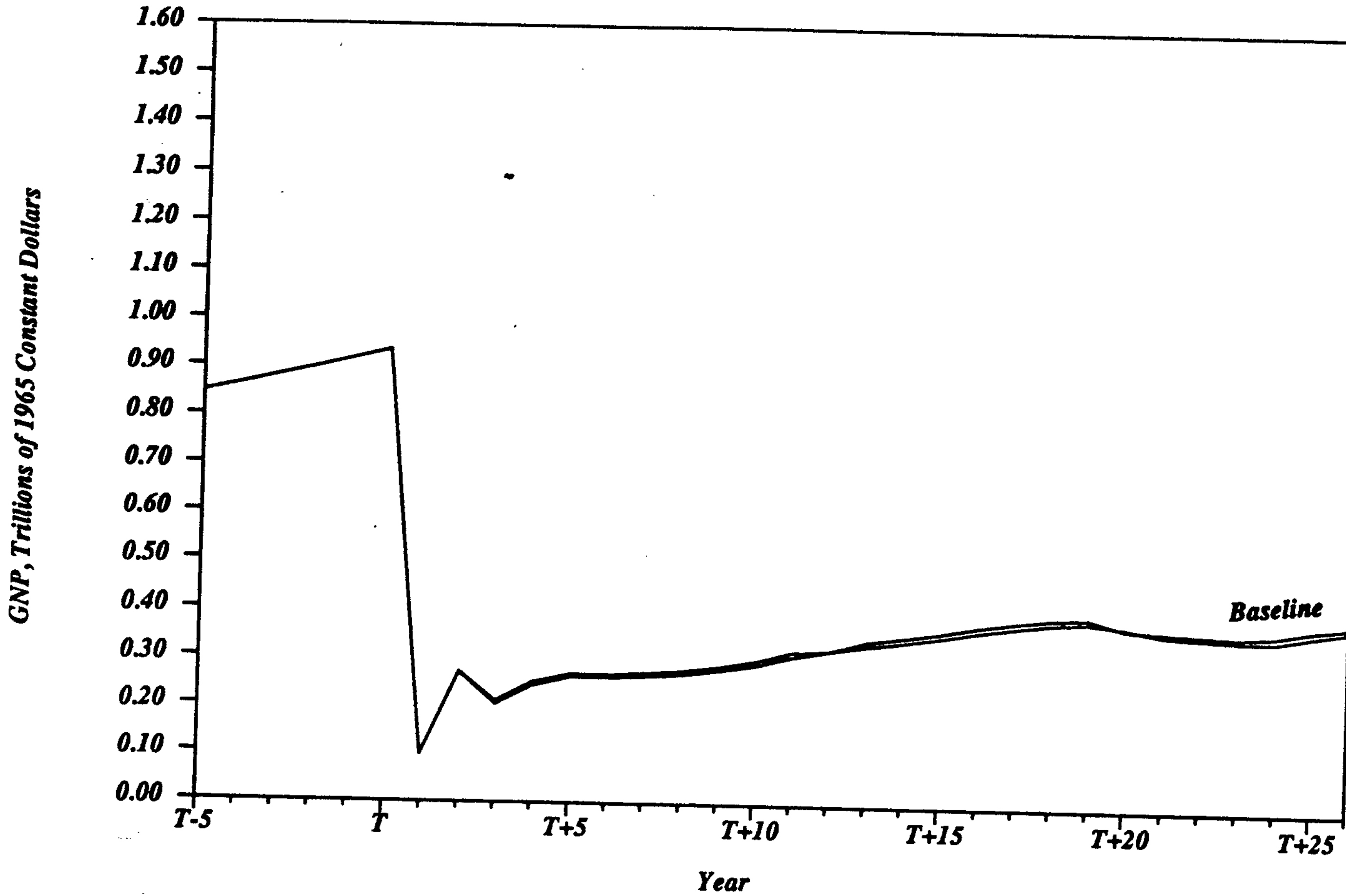
mild psychological effects

Compared to the counter-energy attack, the counter-energy, counter-industry attack should make it more difficult to import goods immediately after the attack and more difficult to rebuild the importing infrastructure. Graph M shows the effect of using the lower import levels discussed previously in producing Graph G: 5% availability of petroleum imports and 15% availabilty of other imports immediately after the attack (with much higher import levels in subsequent years). As before, this has only the slightest effect on the result of the attack.

This attack causes the loss of more than three quarters of the primary metals sector, as well as significant portions of other key industries like motors, generators, engines, turbines, and semi-conductors. Clearly this would severely complicate efforts to rebuild petroleum refineries or retool transportation capital. Our optimistic baseline assumption that transportation capacity equals demand in about one year seems particularly conservative following the counter-energy, counter-industry attack. Graph N considers the result of a a longer time-lag: transporation capacity exceeds demand in about two years. In this case, GNP shows only the slowest level of growth in the 25 years after the attack.

Finally, we examine the effect of reducing the fatality rate and increasing the injury rate following the counter-energy attack. We believe our model for casualties is more realistic than other casualty models, while still being conservative. Nevertheless, for a variety of reasons, it does tend to yield a high percentage of fatalities [9]. In the baseline case we had about 29 million initial fatalities and 7 million injuries. A real attack would probably have a higher casualty rate, with the

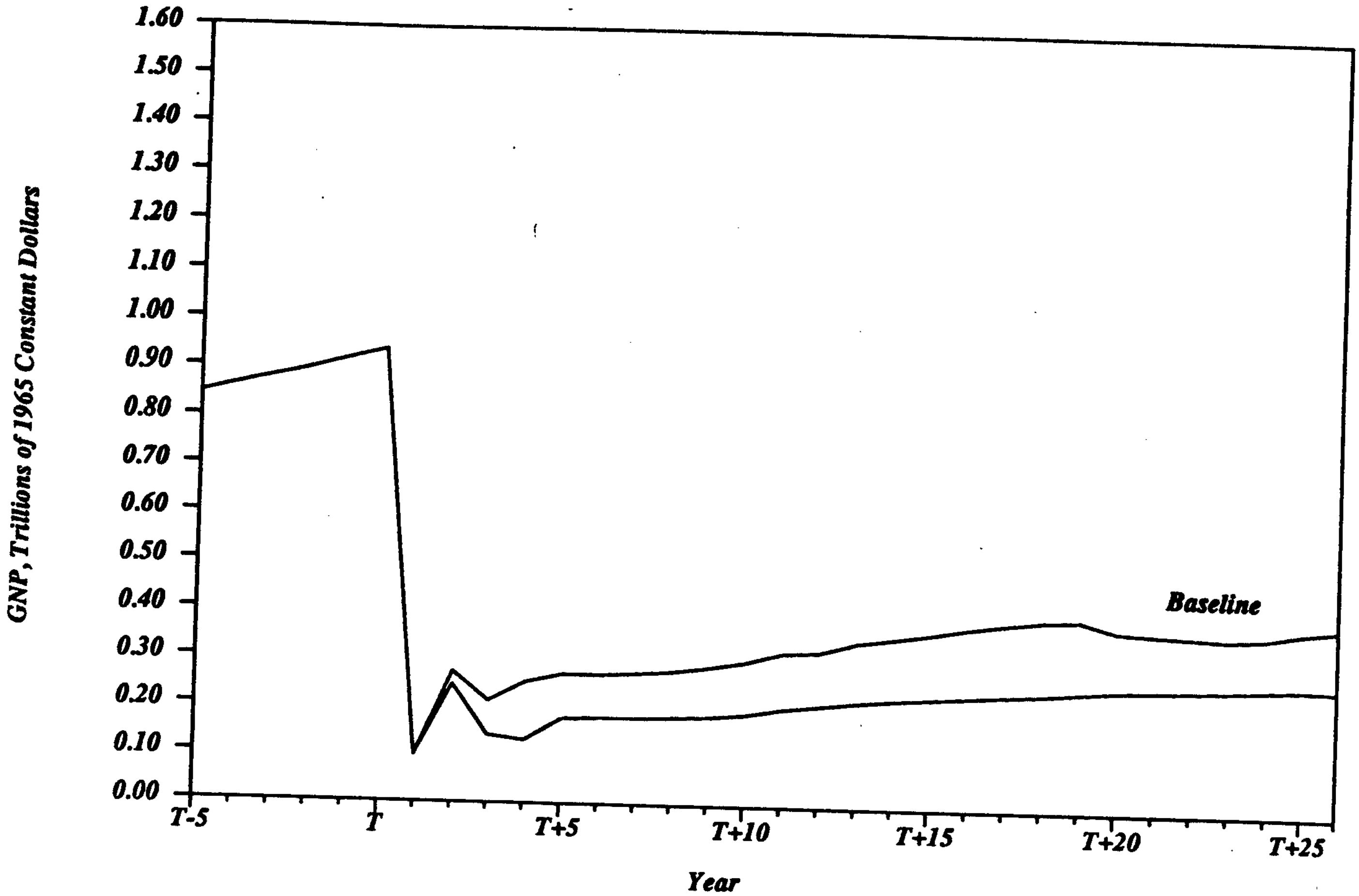
GRAPH M



Counter-Energy, Counter-Industry Attack

all imports reduced

GRAPH N



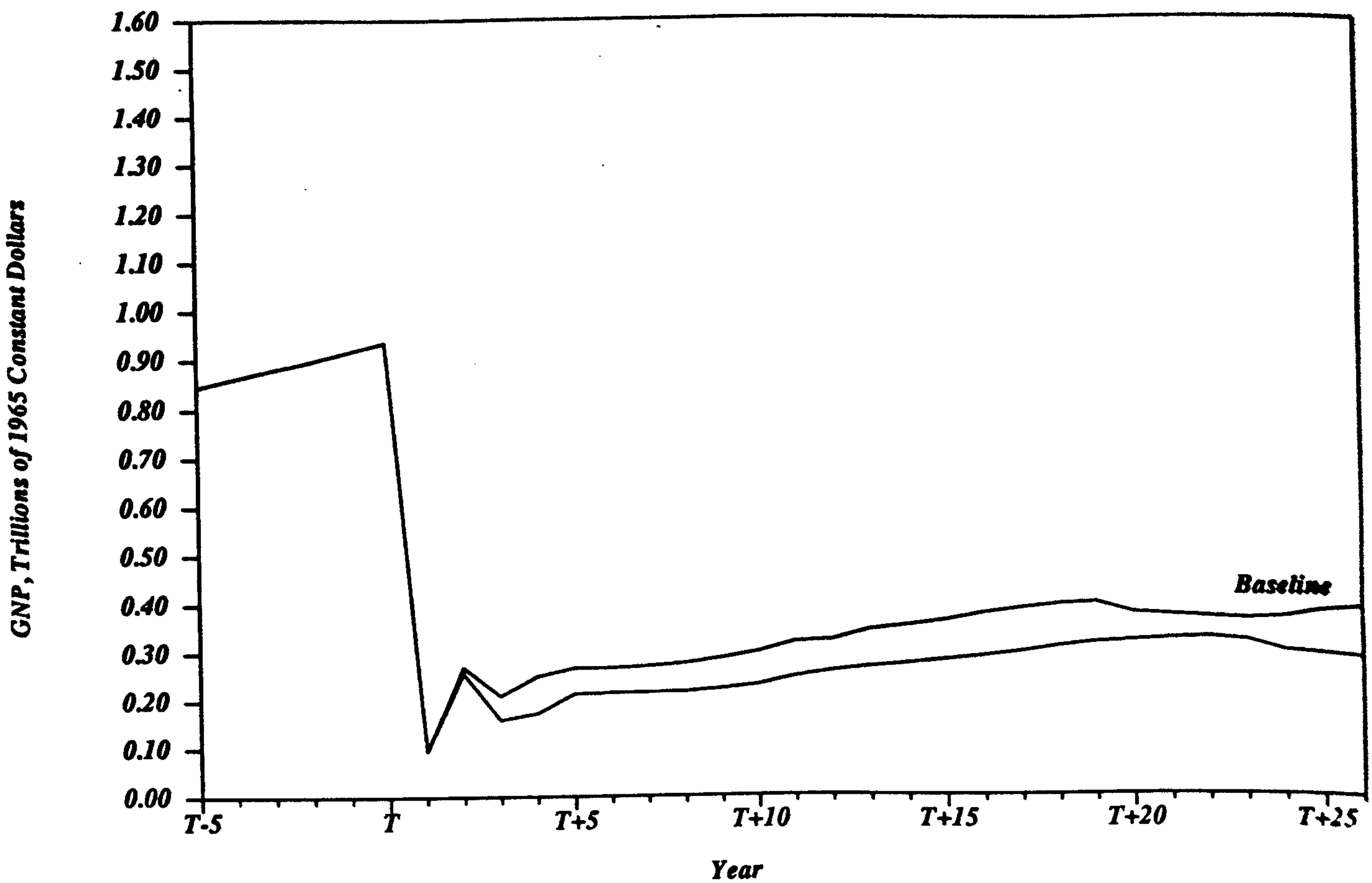
Counter-Energy, Counter-Industry Attack

slower rate of transportation reconnection difference made up primarily of injuries. To examine the effect of a higher injury rate, we consider the baseline attack with the same casualty rate, but this time with 50% fatalities (18 million) and 50% injured (also 18 million). The results are shown in Graph O. GNP is consistently lower and appears never to catch up with the baseline level -- despite the fact that there are more survivors in this scenario. The factors influencing this are explained in Chapter Four; briefly, it is because the injured exert a considerable drain on the economy before they can contribute to recovery -- and by that time, irreparable damage has been inflicted in the vulnerable early post-attack years.

If mild psychological effects are combined with slower reconnection of transportation (without even considering lower imports or more injuries), the FEMA model indicates that the counter-energy, counter-industry attack collapses the economy in a few years. We believe this is the most realistic and most likely result of such an attack.

GNP, Trillions of 1965 Constant Dollars

GRAPH O



Counter-Energy, Counter-Industry Attack

50% of casualties injured

CONCLUSION

This analysis of the FEMA model indicates that the U.S. economy can be severely damaged by small, bottlenecking attacks that consume as little as 1% of the Soviet strategic nuclear arsenal. Because we have made so many optimistic assumptions in arriving at that result, we believe that economic collapse would probably occur at an even smaller level of attack.

We have a variety of conclusions to offer:

A) In the smallest, most optimistic cases considered here, the economy survives at under a third of its pre-attack level. It is far from clear that such a level of activity represents the functioning of a nationally integrated, complex economy as we have come to know it. It is also very unlikely that the economy can climb above pre-attack levels before decades have passed. In qualitative terms, the economy is unable to "shake off" the effects of the initial attack. Built into the FEMA model is the assumption that a nuclear attack will not alter the fundamental structure and interrelationships of the economy. This implicit structural and institutional stability may be obscuring the probability of a total economic collapse during downturn. Certainly, national strategic policy cannot be based on the premise that the U.S. economy can assuredly survive and then recover from the kinds of small attacks we consider here.

B) While computer simulations can be quite misleading, we believe we understand the flaws in at least one previous model (the SRI model, which was essentially designed to show economic recovery) and we believe that the FEMA model (and our implementation of it) minimized or avoided those flaws. The results the FEMA model most reliably produces are qualitative ones — that small attacks can collapse the U.S. economy, or, at least, induce long term stagnation at subsistence levels. These results are markedly different from earlier simulations using different models.

C) The Soviet Union is in no better position than the United States. Although we do not have the FEMA model which simulates the centralized Soviet economy, it is expected that in every important category the Soviet Union is more vulnerable than the United States: their urban population is more than double ours; their ability to feed their population in peacetime is far below ours; their industry is both more concentrated and more extensively collocated with their urban population, and it has minimal redundancy; their petroleum industry in particular is more concentated. More qualitatively, since the centralized Soviet regime exercises a repressive hegemony over most of its population, the Soviet Union would seem much more likely than the U.S. to fragment, or regionalize, after a small nuclear attack under the centrifugal forces of nationalism.

D) Since the Reykjavik summit, drastic reductions in the numbers of weapons on both sides has seemed possible. If both sides can agree to maintain only a force capable of inflicting "unacceptable damage" on the other side, for the purposes of deterring attack, then we conclude both sides could reduce their arsenals by more than 95% [1].

E) Finally, we conclude that the Strategic Defense Initiative is a worthless expense if it is intended to be a protective shield that could keep the country from collapsing under Soviet attack. The number of weapons that could devastate this country is simply too small. A 99% effective defense would not do the job. And even if the proposed anti-ballistic missile system were to do the impossible and be 100% effective, the Soviet Union could still collapse the U.S. economy using cruise missiles and bombers, for example, which the SDI systems are not intended to defend against. Neither will SDI provide a significant area defense against depressed-trajectory submarine-launched ballistic missiles. Since the vast majority of liquid fossil fuel facilities are on or near the coasts of the country, they can easily be attacked from submarines.

By its emphasis on the analytical representation of quantitative economic effects, this report tends to obscure the human side of a post-attack world. Because it is difficult to quantify, this human dimension has been neglected, possibly ignored, in many previous studes on the effects of nuclear weapons on the population. Yet, as the Office of Technology Assessment wrote [2], "The effects of a nuclear war that cannot be calculated are at least as important as those for which calculations are attempted."

The same is certainly true of this simulation. There is simply no objective way in which we could reliably incorporate into the FEMA model the effect of the initial psychological shock of death and devastation on people; the continuing fear of renewed attack; the realization that a way of life has ended; the constant fear that any food, any water, might be fatally contaminated, either by radiation from ground bursts or by toxic chemical leaks caused by the initial attack. Neither can we quantify the adverse effects on children — and hence future generations — caused by exposure to radiation, lack of food, the loss of schools and universities, and the psychological scars of the ordeal.

We have not considered these effects in calculating our baseline results, and indeed we have omitted all adverse psychological effects, not because we do not believe that they are important, but because we cannot predict what their actual extent will be after an attack. And yet, even without taking them into account, the FEMA model indicates that very small Soviet attacks can devastate the U.S. economy. The inclusion of psychological effects at modest levels results in rapid and inexorable economic collapse after even the smallest attacks we consider.

Following a small enough attack, perhaps two or three dozen weapons, the national economy could probably be rebuilt. A larger attack, two or three hundred weapons in size, would result in the national economy fragmenting into disjointed regional economies. Because the FEMA model is a national economic model, its predictions of economic collapse following limited nuclear attacks do not signify the disappearance of all economic activity in the United States, but rather the fragmentation of the economy into regional sub-economies. We identify the counter-energy attack that requires 1% to 2% of the Soviet arsenal with such an effect. Immediately following this attack, the majority of Americans would be alive, but the national transportation network would rapidly collapse, causing millions of urbanites to starve to death and forcing millions of others to migrate from urban industrial centers, both targeted and untargeted, to the relatively undamaged agricultural regions to avoid a similar fate. That, of course, would greatly impede recovery; it is the model's prediction, however, if we represent the flight of the urban population with the presence of mild to moderate psychological effects.

We do not believe that the FEMA model is capable of predicting precise quantitative results, but rather can reveal qualitative trends; nevertheless, the drastic results we obtained even when we used the most conservative assumptions -- those which would tend to overestimate the chances of recovery -- suggest that in fact a smaller attack than the counter-energy attack would probably collapse the US economy.

While the counter-energy attack would probably fragment the national economy into isolated regional economies, after a still larger attack individual communities would be on their own. We may associate this attack with the 60/40 attack that requires about 5% to 6% of the Soviet arsenal; in this attack, most urban-dwelling Americans would be killed or injured immediately, and every region of the country would be so heavily targeted that only individual, untargeted communities have a significant chance of survival. Even those communities would probably be overwhelmed by incoming, injured survivors and by the privation caused be a collapsed national economy.

Since the outcome of attacks involving more than 10% of the Soviet strategic arsenal appears evident, by mere extrapolation, we have kept our analysis to the small attacks for which there have been no reliable estimates of aftereffects.

It bears repeating that we are not suggesting that the Soviets are actually planning "tiny" attacks on the U.S. like the counter-energy attack, but rather we are trying to show just how vulnerable the U.S. economy is to nuclear attack. Nevertheless, we consider our scenarios no less realistic than many (if not most) of the other scenarios widely discussed for a Soviet nuclear attack.

One of the original purposes of the FEMA model was to examine the usefulness of civil defense. Our analysis suggests the existence of several serious problems with civil defense, aside from the logistical difficulties its preparation would entail. Since the attacks required to devastate the United States are so small, the Soviets can easily increase their attack size to thwart any civil defense measures. In fact, the Soviets would not even have to increase the attack size if they were to choose to destroy ports and the petroleum industry, which would cripple nationwide transportation. In that case, many survivors die of starvation, and civil defense would probably make little difference in the long run.

As discussed earlier, recent research has shown that there has been a tremendous underestimation of the effects of nuclear detonations on people and buildings. This report attempts to complement this reexamination of nuclear weapons effects by showing that there has been a similar underestimation of the effects of tens to hundreds of weapons on the national economy. At the root of many of the most poorly conceived ideas and mistaken nuclear strategies is the notion that the effects of a few dozen weapons would be "tolerable" — a notion based on an underestimation of the persistence and extent of their devastating effects on an integrated, strongly interactive economy. We hope that our presentation of the more realistic predictions of what even a very few nuclear weapons can do to a nation will form the basis of policy decisions regarding the future size and composition of the nuclear arsenals of the United States and the Soviet Union.

FOOTNOTES

INTRODUCTION

1. Of the extensive literature on the subject, these are the works we referred to most:

S. Glasstone and P. Dolan, eds., *The Effects of Nuclear Weapons*, Government Printing Office, 1977.

Congressional Office of Technology Assessment (OTA), *The Effects of Nuclear War*, Government Printing Office, 1979.

Arms Control and Disarmament Agency (ACDA), *An Analysis of Civil Defense in Nuclear War*, ACDA, 1978.

W. Daugherty, B. Levi, and F. von Hippel, "The Consequences of 'Limited' Nuclear Attacks on the United States," *International Security*, Spring 1986.

T. Postol, *Possible Fatalities from Superfires following Nuclear Attacks in or Near Urban Areas*, paper presented at the Insitute of Medicine's Symposium on the Medical Effects of Nuclear War, National Academy of Sciences, Washington D.C., September 20-22, 1985.

AMBIO, Nuclear War: The Aftermath, Volume XI, Number 2-3, 1982.

A. M. Katz, *Life After Nuclear War*, Ballinger, 1982.

R. Goen, R. Bothun, and F. Walker, *Potential Vulnerability Affecting National Survival* (PVANS), Stanford Research Institute (SRI), September 1970.

F. Dresch and S. Baum, *Analysis of the U.S. and USSR Potential for Economic Recovery Following A Nuclear Attack*, Stanford Research Institute, 1973.

Economic Model commissioned by Federal Emergency Management Agency as described in *Development of a Dynamic Model To Evaluate Economic Recovery Following a Nuclear Attack, Final Report, Volume I: Description and Simulations*, November 1980, Pugh-Roberts Associates, Inc, Cambridge, MA.

2. Dresch and Baum, SRI *Analysis*, op.cit.

Many other studies *have also* attempted to calculate the recovery time for the U.S. following a given attack. For instance, in "Central War and Civil Defense" published in *Orbis*, Fall 1978, T.K. Jones and W. Scott Thompson suggest that, using *35%* of its deployed strategic force, the Soviet Union "could impose, for example, a twenty-year penalty on the United States."

Chapter One

1. OTA report, op.cit.

2. Glasstone and Dolan, op.cit. Throughout this chapter, this book is the primary source for the blast, heat, and radiation contours for nuclear detonations. The OTA report, op.cit, was also a source. It is true that for the larger weapon, the heat is deposited over a longer period of time, but this only slightly reduces its effect (relative to less heat deposited over a shorter period of time.

3. T. Postol, op.cit.

4. ACDA, 1978, op.cit., p. 3.

5. The Soviets have, roughly, 6000 megatons, whether calculated as equivalent megatons or absolute megatons. The 170 550-kiloton weapons used in the attack constitute some 115 equivilent megatons (slightly under 2% of 6000), and some 94 absolute megatons (slightly more than 1.5% of 6000).

6. E. J. Lerner, "EMPs: Potential Crippler" IEEE Spectrum, May 1981.

7. Katz, op.cit., pp. 91-142. The primary modification we made in the attack is that we replaced the 1-megaton weapons he uses with 550-kiloton weapons. Since he has used overly conservative damage criteria, this switch has, we believe, no effect on the outcome of the attack as Katz describes it.

8. We used the Census of Population's 1980 United States Summary: Number of Inhabitants to establish the population and areas of the 481 cities, towns, suburbs, and villages that are targeted in this attack.

9. It may very well be that there are many millions more injured. We examine this possibility in Chapter Five.

Chapter Two

1. Joint Committee on Defense Production, Civil Preparedness Review Part II: Industrial Defense and Nuclear Attack, U.S. Government Printing Office, 1977.

2. J. Sassen and K. Willis, Data Base and Damage Criteria for Measurement of Arms Limitation Effects on War Supporting Industry, Metis Corporation for the Arms Control and Disarmament Agency, 1974.

3. S. G. Winter, Economic Recovery From the Effects of Thermonuclear War, RAND Corporation, Santa Monica, California, 1961.

4. War Supporting Industry report for ACDA, op cit.

5. One problem in World War II with bombing high-value German targets was that selective sites could be provided with heavy air defenses, making their destruction too costly in terms of Allied aircraft and airmen. Today, however, destroying high value targets with nuclear weapons avoids that problem of strategic bombing.

6. German chief electrical engineering designer quoted in Bennett Ramberg, Destruction of Nuclear Energy Facilities in War, Lexington Books, 1980, pp. 13-14.

7. ACDA report, 1978, op.cit.

8. Marketing Economics Insitute Key Plants 1984-1985, Marketing Economics Institute, 1985. Our calculations involved rounding numbers to the nearest whole percentage point. We checked the accuracy of this data base against Census Bureau subtotals for four-digit SIC codes and found the agreement to be within 5% or so in most cases. Perhaps because of economies of scale or attempts to cut transportation costs by locating near suppliers or markets, the trend in U.S. industry seems to be towards greater concentration -- which implies that our figures probably err on the side of underestimating the degree of concentration of U.S. industry.

9. The inadequacy of the surviving medical community has been discussed extensively elsewhere. See, for instance, Katz, op.cit., for discussion and references. Also see, J. Leaning and L. Keyes, The Counterfeit Ark, Ballinger, 1984.

10. Katz, op.cit., pp. 179-180.

11. In this section, we use the following sources:
Energy Information Administration, Department of Energy, Monthly Energy Review: December 1986, Government Printing Office, March 1987.
Bureau of Economic Analysis, Department of Commerce, Summary Input-Output Tables of the U.S. Economy, Govenrment Printing Office, Oct. 1981.
Bureau of the Census, Department of Commerce, Annual Survey of Manufactures (Fuel and Electric Energy consumed), Government Printing Office, 1985.

Oak Ridge National Lab, Transportation Energy Data Book, O.R.N.L. (for the Department of Energy), Sixth Edition, 1982.

Oak Ridge Associated Universities (for the Department of Energy), Industrial Energy Use Data Book, Garland, 1980.

Office of Technology Assessment, U.S. Vulnerabiliy to an Oil Import Curtailment: The Oil Replacement Capability, U.S. Congress, Office of Technology Assessment, 1984.

National Petroleum Council, Emergency Preparedness for Interruption of Petroleum Imports into the U.S., 1981, pp. 24, 28-29, 73, 111.

A. B. Lovins and L. H. Lovins, Brittle Power, Brick House, 1982.

Eliot Marshall, "Planning for an Oil Cutoff," Science, vol. 209 pp. 246-247, 11 July 1980.

American Enterprise Forum, J. C. Daly, moderator, Energy Security -- Can We Copy with a Crisis?, American Enterprise Institute, Nov. 1980.

W. Clark and J. Page, Energy, Vulnerability and War, Norton, 1981.

D. A. Deese and J. S. Nye, Energy and Security, Harvard Energy and Security Project, Ballinger, 1981.

12. Many of the weapons targeted on active refineries destroy inactive ones incidentally (inactive refineries were identified by comparing lists of operating refineries for several years, and deducing which ones had fallen out of use). With the addition of a few more weapons, most of the refineries that currently lie unused would be destroyed. Reopening shut refineries can be difficult even under the best circumstances.

13. Winter, op.cit.

14. V. Krishnamurthy, India's Secretary for Industry, as quoted in "Growing Energy Gap in India is Crippling Industry," New York Times, Dec. 16, 1979, p. 24.

15. Alvin Alm, quoted in Eliot Marshall, op.cit.

16. Eliot Marshall, op.cit.

17. National Petroleum Council, op.cit.

18. In its Monthly Energy Report for 1986 (op.cit.) the Department of Energy reports that existing petroleum stock, in transit, terminals, pipes, etc., totals 1.6 billion barrels -- out of an annual usage of 16.1 billion barrels.

19. Oak Ridge Associated Universities, Industrial Energy Use Data Book, op.cit.

20. K. Tsipis and S. Fetter, "Catastrophic Releases of Radioactivity," Scientific American, April 1981.

21. It might be argued that the Soviets, understanding the devastating global possibilities of a nuclear winter scenario, would try to avoid targets such as oil refineries, that could cause superfires that might make nuclear winter more likely. Yet, the most recent and comprehensive work on nuclear winter suggests that it would probably require an attack more

than 10 times larger than the counter-energy attack to have significant global impact. Moreover, if the Soviets were concerned, the extreme geographic concentration of U.S. refineries would allow the Soviets to use ground bursts near the refineries rather than overhead air bursts on them, to render them unusable with radioactivity rather than fires.

Chapter Three

1. We are indebted to John Sterman of the Sloan School of Management at M.I.T. for his insightful comments on the subject covered here. Although the material that appears here is our own, his paper A Skeptic's Guide to Computer Models (Sloan School of Management, MIT, 1985), was extremely enlightening and did inspire the first section of this chapter.

2. Nuclear Winter and the Club of Rome's dire prediction of resource limitations (see, for instance, Meadows et al, Limits to Growth, Universe Books, New York, 1972) are both examples of well-publicized, controversial results based on computer models.

3. SRI report, 1973, op.cit.

4. Ibid, p. I-2.

5. Ibid, p. I-12.

6. Ibid, p. I-16.

7. Ibid, p. I-12.

8. Ibid, p. I-16.

9. Ibid, p. I-11.

10. Perhaps the majority of one-megaton weapons targeted on refineries could be replaced by 100- or 200-kiloton warheads, drastically reducing the overall megatonnage of the attack.

11. Pugh-Roberts Associates Inc., Development of a Dynamic Model, op.cit.

12. The equations that make up a System Dynamics model consist of representations of decision-making, both individual and corporate, which in the aggregate explain and predict macroeconomic phenomena. For example, in an econometric model, the demand for a primary factor (such as a raw material required by a manufacturer) would be derived from an aggregate production function using statistical methods which correlate the historical demand for the raw material to other empirically-measured variables (such as the amount of other raw materials available). In a System Dynamics model, the same primary factor demand is determined by an ordering function relating the factors that would influence a factory manager's ordering decision. The manager's decision could be influenced by inventories, the order backlog for the material ordered, delivery delays, perceived prices, expected process, expectations of the market's stability and desired production rates. The ordering function could take a non-linear form, influenced by economic conditons, and corresponds directly to the "rules of thumb" or decision rules employed by managers and shop foremen in making such descisions. Because decision-making is the focus rather than its usual aggregate results, this technique is probably better suited to represent the behavior of agents in the economy under unusual conditions of low availabilty of some factors and adequate supplies of

others, of extreme price fluctuations and of uncertain desired production rates.

13. Office of Technology Assessment, U.S. Vulnerability to an Oil Import Curtailment, op.cit.

14. Department of Commerce, Survey of Current Business, Government Printing Office, April 1979.

15. This discussion of psychological effects is adapted from the Pugh-Roberts report on the FEMA model, op.cit.

Chapter Four

1. Yves Laulan, "Economic Consequences: Back to the Dark Ages," AMBIO, vol XI, no. 2-3, 1982.

The example of the Japanese and German economies toward the end of and immediately after the Second World War (which would resemble only the most unrealistically optimistic post-nuclear attack scenarios) illustrates the potential disruptiveness of an attack that obliterates industry. For example, in a 1963 Rand Corporation study Disaster and Recovery: A Historical Survey, J. Hirshliefer notes that the Japanese recovery was unsatisfactory — slower than the planners had anticipated — because of "the diversion of production and exchange into devious and inefficient channels to evade price control and allocation mechanisms." The black market may have accounted for as much as half of the national income in these years. Urban Japanese trekked into the countryside to barter for food, and the fact that agricultural output recovered faster than industrial implied an unplanned shift of population, and hence economic activity, out of the cities.

In Germany, in the aftermath of the war, "transportation had generally stopped, and with it practically all industrial production." From May to December 1945, industrial production was as low as 5% of its normal level, despite the fact that industrial damage was estimated at 20% of the pre-war capacity. And until 1948, the nation was unable to focus on industrial recovery: "economic planning in Germany was dominated by the hand-to-mouth problem of finding sufficient food to prevent starvation."

2. Such scenarios include the smallest of the attacks SRI considered in their 1973 report, op.cit.

Chapter Five

1. Water Resources Support Center, U.S. Corps of Engineers, Port Series, Government Printing Office, 1983-84.

2. Assistant Secretary for Fossil Energy, Department of Energy, Strategic Petroleum Reserve: Annual Report, Government Printing Office, 1984.
R. G. Lawson, "Strategic Petroleum Construction Ends First Phase," Oil And Gas Journal, 21 July, 1980.

3. Aileen Cantrell, "Annual Refining Survey," Oil and Gas Journal, March 1983, 1984 and 1985.

4. Penn Well Maps, Product Pipelines of the United States and Canada, Penn Well Publishing, 1983.
Penn Well Maps, Crude Oil Pipelines of the United States and Canada, Penn Well Publishing, 1982.
Penn Well Maps, Natural Gas Pipelines of the United States and Canada, Penn Well Publishing, 1982.

5. We criticized the SRI report in Chapter Three for having all of the destroyed refining capacity come back in exactly 2 years. This is both optimistic in terms of speed, and unrealistic in terms of simultaneity. We have kept the optimistic aspect of the speed of return of transportation capital, but we have tried to handle it more realistically. We optimistically have transportation capacity equal deman about one year after the attack, yet the entire rebuilding process is spread over a three year period.

6. As discussed in Footnote 1 of Chapter 4, this happened to some extent in both Japan and Germany after World War II.

7. Imports cannot be relied on forever. If imports become an external crutch for the U.S. economy, then the internal rebuilding process can be slowed down, which can seriously hurt the long-term prospects for the economy.

8. As we have said before, if the point of the attack is to collapse the U.S. economy and keep it from recovering, the Soviets might well target a few weapons on Canada and Mexico to put them in no position to aid the United States, at least in the short term when it is the most critical.

9. As described in the text, our casualty rates for an evenly distributed population is 70% fatalities, 30% injuries. In the case when the bomb is dropped on an urban center, where the population is concentrated near ground zero, fatality rates will be higher. While we believe that an attack like the 60/40 attack, which targets many weapons (up to 60) on an individual city, we are confident that our high fatality rates are realistic. For the smaller attacks, like the counter-energy attack, where in many cases only one weapon is targeted on a city, it is entirely possible that there would be more injuries than we calculate. Perhaps the higher injury rate would mean a lower fatality rate, but not necessarily. We believe our overall casualty rate is conservative, and it may very well

be that injuries occur over a much larger area than we use in our approximation (especially if some weapons are ground-burst, and radiation is widespread). In any case, as the FEMA model indicates, our choice of a high fatality rate is an optimistic one from the viewpoint of economic recovery.

Chapter Six

1. We have argued that only 1% of the arsenal is required to inflict "unacceptable damage." This would imply reductions of 99% or more could be made. Yet, allowances have to be made for certainty of delivery, both from the point of view of weapons reliability, and from the point of view of survivability (for instance, some of the U.S. deterrent could be destroyed in a Soviet first strike). For this reason, we have chosen a conservative figure of 95% reductions.

2. OTA, The Effects of Nuclear War, op.cit.

Additional Bibliography

ACDA, The Effects of Nuclear War, ACDA, 1979.

B. W. Bennett, Assessing the Capabilities of Strategic Nuclear Forces: The Limits of Current Methods, Rand Corporation (for the Office of the Secretary of Defense), 1980.

Congressional Hearings before the Joint Committee on Defense Production, Civil Preparedness and Limited Nuclear War, Government Printing Office, 1976.

Congressional Hearings before the Joint Committee on Defense Production, Civil Preparedness Review, Parts I and II, Government Printing Office, 1977.

J. M. Chenowith, L. A. Hoh, R. C. Hurt, and L. B. McCammon, A Method for Predicting Electrical Power Availability Following a Nuclear Attack, Office of Civil Defense, 1963.

Defense Civil Preparedness Agency, Attack Envirnoment Manual, D.C.P.A., 1973.

S. Drell and F. von Hippel, "Limited Nuclear War," Scientific American, May 1978.

J. C. Greene, R. W. Stokely, and J. K. Christrian, Recovery from Nuclear Attack, and Research and Action Programs to Enhance Recovery Prospects, International Center for Emergency Preparedness (for FEMA), 1979.

R. W. Krupka, Collateral Damage, Hudson Institute, 1963.

F. Ikle, The Social Impact of Bomb Destruction, University of Oklahoma Press, 1958.

J. Leaning and L. Keyes, eds., The Counterfeit Ark, Ballinger, 1984.

K. N. Lewis, "Prompt and Delayed Effects of Nuclear War," Scientific American, July 1979.

R. J. Lifton, Death in Life, Vantage, 1969.

National Academy of Science, Project Harbor Summary Report, N.A.S., 1964.

J. W. Russel and E. N. York, Expedient Industrial Protection Against Nuclear Attack, The Boeing Company, March 1980.

J.W. Sinko and L. D. Bryson, The Recovery of Cities From Major Disasters: A Conceptual Model, SRI International (for U.S. Army Missile Command), 1970.

U.S. Strategic Bombing Survey, Effects of Strategic Bombing on German Morale, Government Printing Office, 1947.

U.S. Strategic Bombing Survey, Effects of Strategic Bombing on the German War Economy, Government Printing Office, 1945.

U.S. Strategic Bombing Survey, Effects of Strategic Bombing on Japan's War Economy, Government Printing Office, 1946.

APPENDIX ONE
ANALYSIS OF THE EFFECTS OF A COUNTER-ENERGY ATTACK

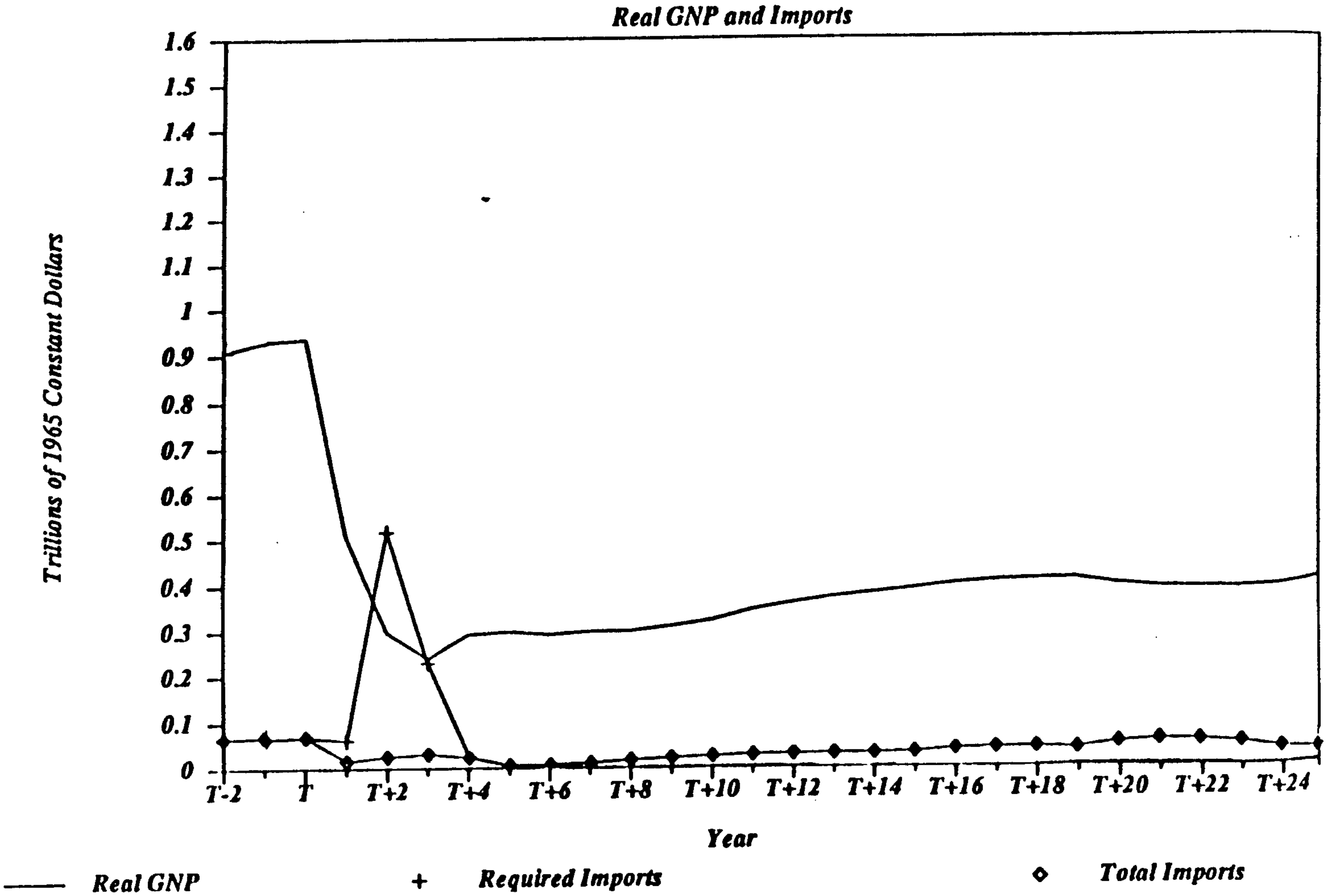
This appendix details the behavior of several key economic variables in the baseline Counter-Energy Attack scenario. The first plot depicts the time development of GNP, required imports, and actual imports. The second plot shows the population levels. Several of the FEMA model's 11 industrial sectors are then explored in detail. For metals, capital goods, energy products, transportation, and agriculture, plots of demand, capacity, and usage are given. Although for these sets of graphs the ordinates are shown as co-linear (all beginning in 1980), they are distinct, as the separate abscissae indicate.

Graph One: The drop in GNP is much greater than would be expected as a result of the direct loss of capacity and inventories. The mechanism for this collapse comes into effect immediately: it is the lack of transportation, demonstrated in subsequent plots.

It is not clear that the economy will recover after 2005, since economic activity remains at 35% to 45% of the pre-attack level for the entire period simulated by the model. This low level of economic activity implies that fundamental structural changes have taken place in the integrated, interdependent structure of the U.S. economy as we know it.

In the second and third years after the attack, import requirements shoot up to over 5 times the normal level. In these post-attack years, the shortages of materials are acute, since over 90% of the U.S. survives

GRAPH ONE

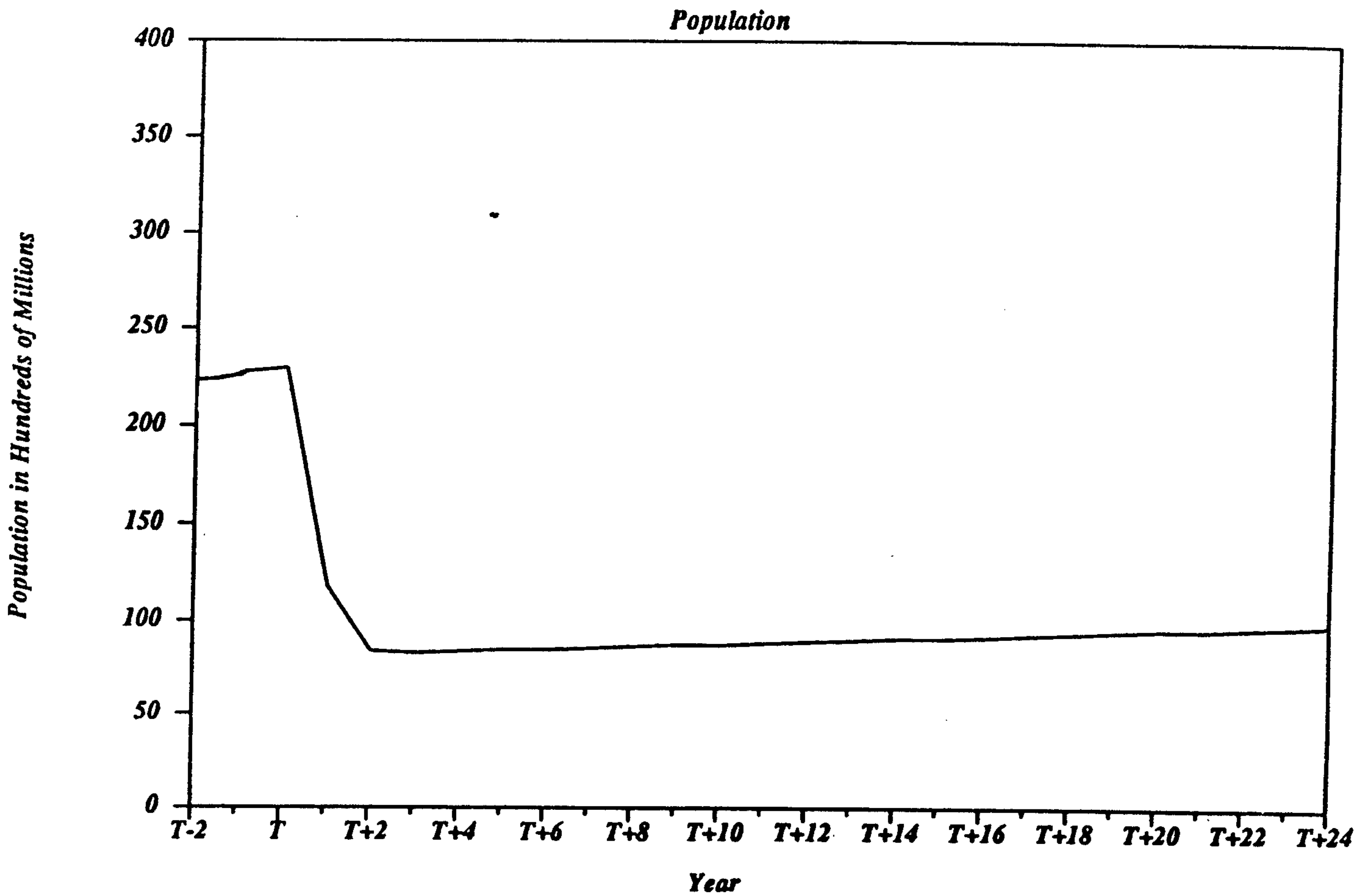

Real GNP and Imports
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Trillions of 1965 Constant Dollars
T-2
T
T+2
T+4
T+6
T+8
T+10
T+12
T+14
T+16
T+18
T+20
T+22
T+24
Year
Real GNP
Required Imports
Total Imports

the immediate physical effects of the attack. The survivors place a huge drain on the badly crippled economy, which, limited by a lack of transportation, simply cannot satisfy the demands placed on it. Imports could partially meet those demands, but, unfortunately, it is physically impossible to bring large volumes of imports into the country. Moreover, as we discuss in Chapter Five, larger initial levels of imports are not always beneficial to the economy in the long run.

The severe shortfalls in food and materials "crash" the economy. Whereas the first huge plunge in GNP is partially due to "accounting losses" — the low GNP reflects the loss of value associated with factories and inventories -- the continued depressed performance of GNP indicates that a real and fundamental change has taken place in the U.S. economy. This and subsequent graphs demonstrate that the U.S. economy cannot really recover from the effects of the counter-energy attack.

<u>Graph Two:</u> As a consequence of the absence of transportation for agricultural products (see Graph II.F), far more people die (about 50%) in the first two years after the attack than are killed by the attack itself (about 8%). Our scenario considers that the attack has no adverse psychological effects; thus, worker productivity is undiminished by the mass starvations and deaths caused by inadequate medical and housing supplies. The starvation in the second and third years after the attack, is a direct result of the lack of transportation available in the initial post-attack period. (See also Chapter Five).

GRAPH TWO



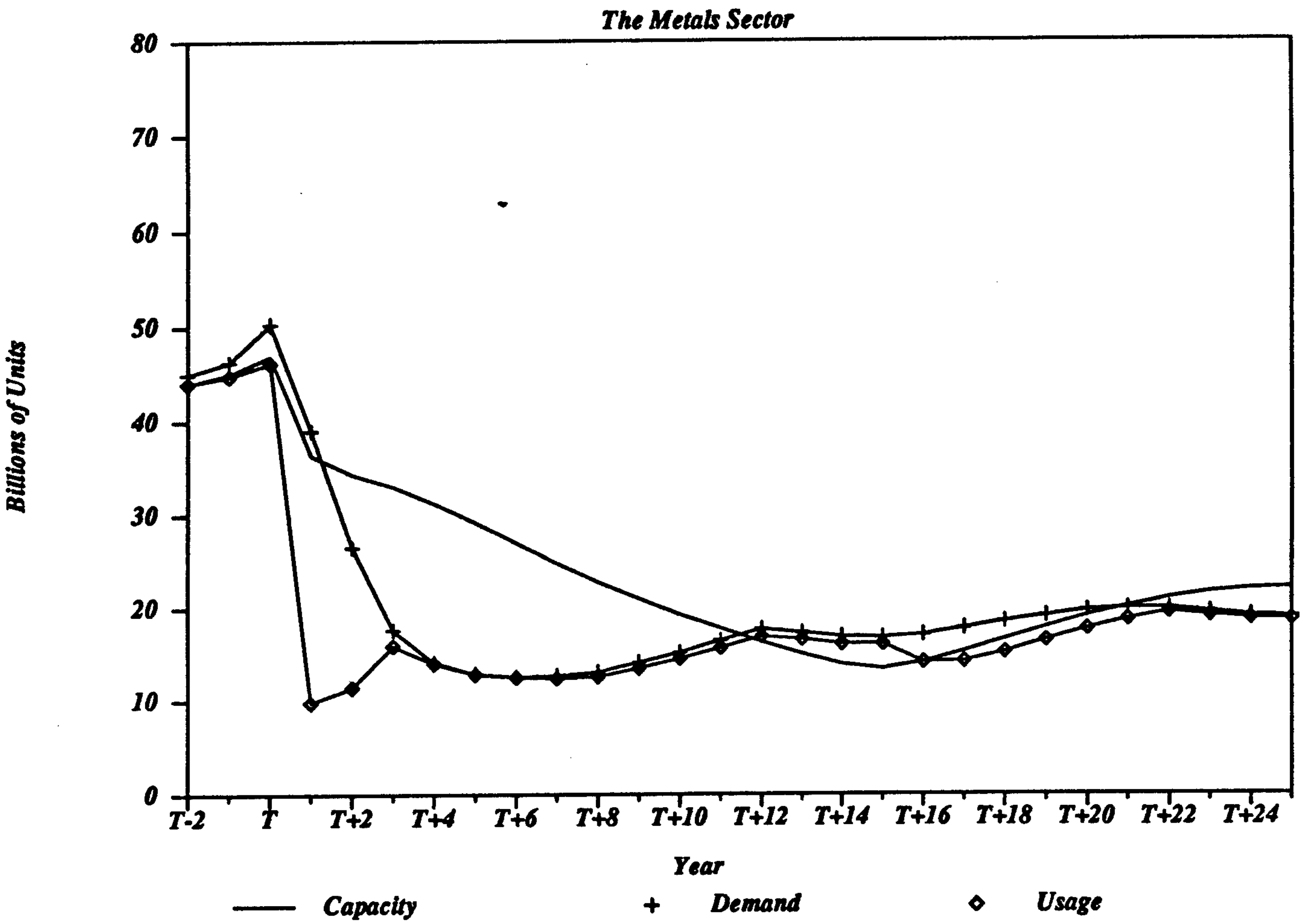
Population
400
350
300
250
200
150
100
50
0
Population in Hundreds of Millions
T-2
T
T+2
T+4
T+6
T+8
T+10
T+12
T+14
T+16
T+18
T+20
T+22
T+24
Year

<u>Graph Three</u>: The huge initial gap betwen demand and usage in the metals-producing sector is caused by the large drop in transportation adequacy resulting from the lack of liquid fuels. Demand then falls (people die, factories shut down) and transportation adequacy rises quickly. All transportation capital is reconnected within about four years, although the ability of the transportation sector to satisfy demand rises even faster because demand is reduced.

Capital stock for the metals-producing sector is not replaced at a rate fast enough to compensate for depreciation, and capacity plunges below usage in 1993. Usage is maintained at a high level for a couple of years, thanks to inventories, but then falls in 1995. The metals-producing sector capacity has begun to increase by 1996 and the situation is corrected; yet the same problems threaten other sectors.

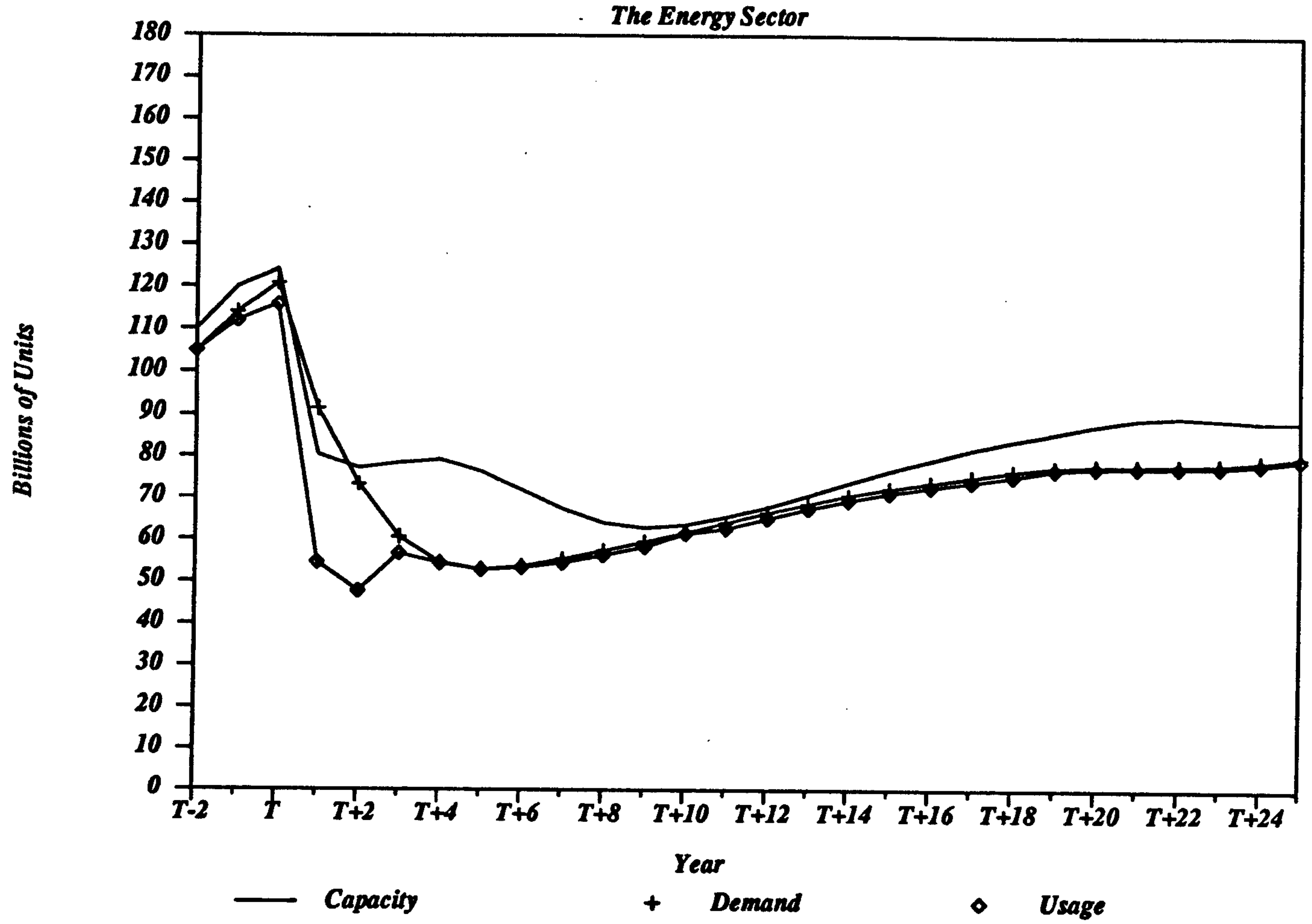
<u>Graph Four</u>: The scenario we use assumes that the energy-products sector has priority over other sectors in the allocation of raw materials and other resources. This policy is consistent with our findings on the importance of energy products for recovery. Thus, this sector is not shown to suffer the large drops in adequacy of vital inputs that other sectors experience. A shortfall in transportation during the first few years after the attack is inevitable, and it is responsible for the large gap between demand for and actual usage of energy products. After this is corrected, however, no extreme imbalances appear, and usage fairly closely follows demand. The price for this stability is reflected in the inadequacies experienced by the other sectors of the economy, yet it seems to us that the policy of favoring the energy sector over others is a sensible plan for

GRAPH THREE



Billions of Units

GRAPH FOUR



The Energy Sector
Billions of Units
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
T-2
T
T+2
T+4
T+6
T+8
T+10
T+12
T+14
T+16
T+18
T+20
T+22
T+24
Year
Capacity
Demand
Usage

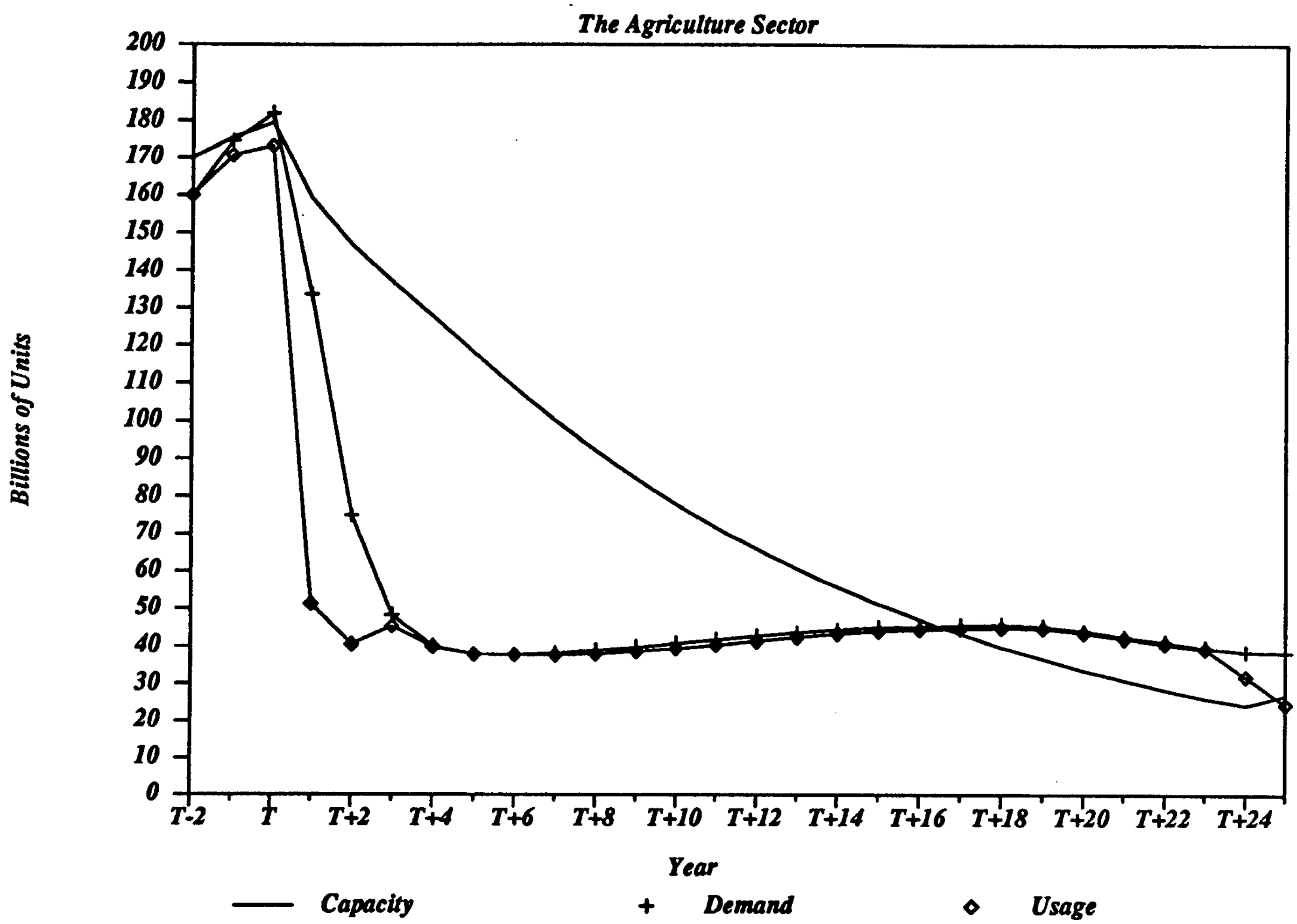
post-attack recovery.

<u>Graph Five</u>: In the agriculture sector, a significant drop in usage below demand has the most drastic effects: people starve. (See Graph Two) In the initial post-attack years, starvation occurs because there are no means to transport food. By 1996, however, capacity has fallen to levels below usage. The nation has, however, fairly large stores of food that are used up in the next six years. When usage falls in 2003, people are threatened with starvation again. A second famine may well occur if enough resources are not directed toward developing the agricultural sector.

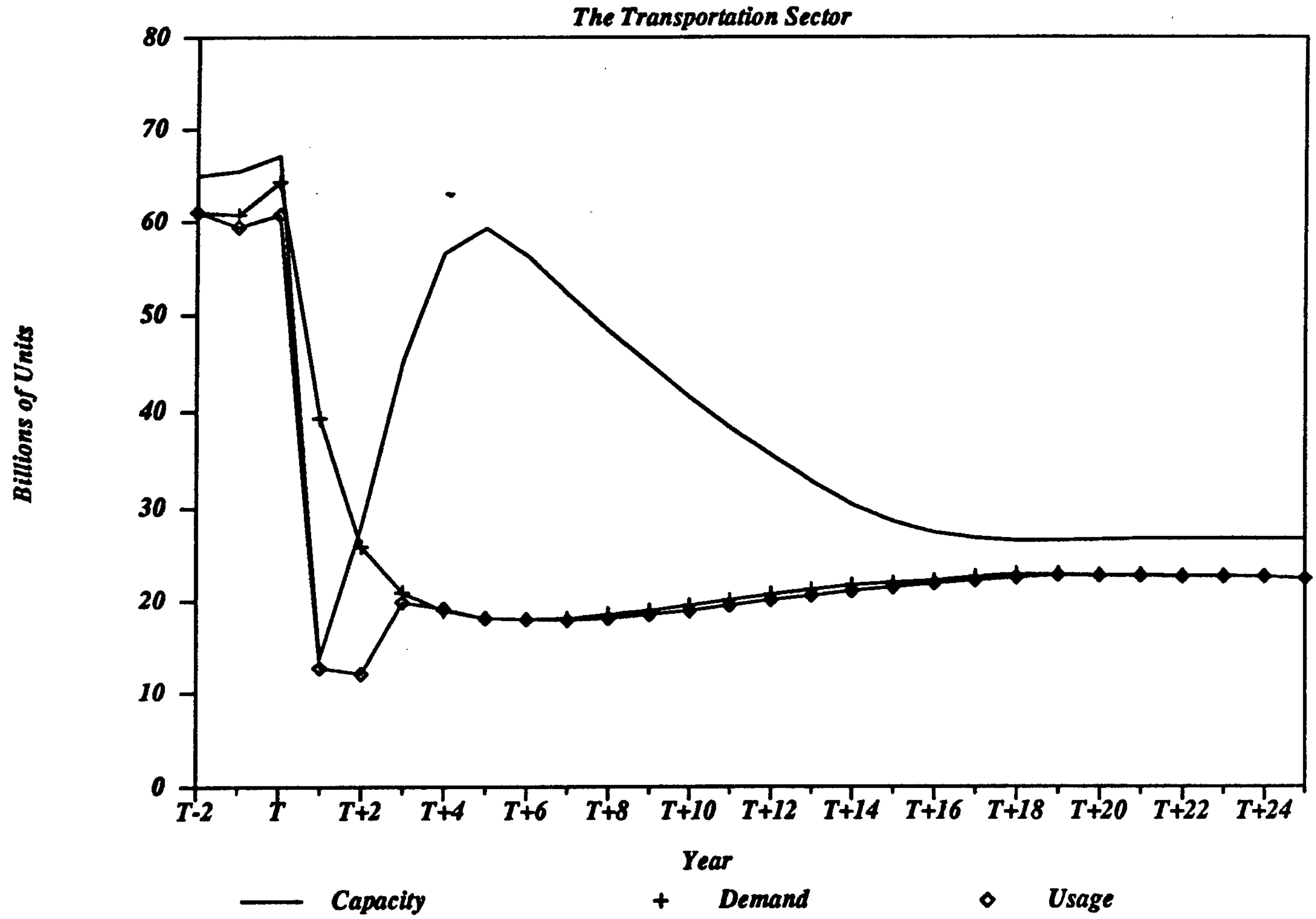
<u>Graph Six</u>: Unlike other sectors, the transportation sector is limited by the lack of available capital in the first years after the attack. By the third year after the attack, available capital has reached a level close to its pre-attack value -- but now both demand and usage remain depressed at a mere third of their pre-attack levels. It is the gap between demand and usage in the initial post-attack years that brings all the other sectors in the economy to a much lower level of activity for the decades that follow the attack. Once the initial "crash" occurs, transportation is no longer a bottleneck blocking recovery -- indeed, there is a considerable excess of transportation capital over 15 years. Such excesses of capital are a dangerous sign: they indicate that the economy is underperforming. Once the transportation shortage had its effect on the economy, other, dynamic changes take place -- the capital squeeze that occurs in the metals sector is an example. The authorities responsible for the recovery effort would find severe capital shortages occurring first in one sector --

Billions of Units

GRAPH FIVE


The Agriculture Sector
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Billions of Units
T-2
T
T+2
T+4
T+6
T+8
T+10
T+12
T+14
T+16
T+18
T+20
T+22
T+24
Year
Capacity
+ Demand
◇ Usage

GRAPH SIX



The Transportation Sector
80
70
60
50
40
30
20
10
0
Billions of Units
T-2
T
T+2
T+4
T+6
T+8
T+10
T+12
T+14
T+16
T+18
T+20
T+22
T+24
Year
Capacity
+ Demand
◇ Usage

transportation -- and then another -- metals. While their efforts were focused on these troubled sectors (these efforts would necessarily mean the diversion of resources from other sectors to those in trouble) problems could develop elsewhere in the economy. Instead of economic recovery, the nation would be faced with a series of threatening crises.

APPENDIX TWO
TARGETS IN THE COUNTER-ENERGY ATTACK

Each row represents one target. Some targets receive multiple weapons.

Alabama

Hoover, Maytown (Birmingham suburb), Vestaiva Hills
Chickasaw, Saraland
Tuscaloosa

Alaska

Anchorage
Big Horn, North Pole
Kenai
Nikisha
Ketchikan, Ketchikan East, Penock Island
Tatilek (near Valdez)

Arkansas

Stephens
El Dorado

California

Alameda, Berkeley, Emeryville, Oakland, Piedmont
Richmond, San Pablo
Hercules, Rodeo
Bakersfield
Kings Country (near Avenal and Kettleman City)
Harbor City, Long Beach Harbor, Los Angeles, San Pedro, West Carson, Wilmington
Lomita, Redondo Beach, Torrance, Wilmington
Carson, West Carson
Long Beach, Signal Hill
Del Aire, El Segundo, Hawthorne, Inglewood, Lawndale, Lennox, Manhattan Beach, South Bay Cities, Westchester
Encino, Los Angeles, N Hollywood, Van Nuys
Sacramento
Coronado, San Diego
San Francisco
Grover City, Pismo Beach
Atherton, East Palo Alto, Menlo Park, Redwood City, San Carlos
Santa Cruz, Twin Lakes
Benecia, Martinez
Ventura
Oxnard, Port Huneme

Colorado

Aurora
Denver, Commerce City, Derby

Delaware
Delaware City

Florida
Panama City, Pretty Bayou
Cape Canaveral, Cocoa Beach
Fort Lauderdale, Hollywood
Miami, Miami Beach
Jacksonville
Goulding, Pensacola
East Tampa, Gibsontown
Tampa
Memphis, Port Manatee
Bay Lake, Lake Buena Vista, Walt Disney World
Mangonia Park, Palm Beach, Palm Beach Shores, Riviera Beach, W Palm Beach

Georgia
Garden City, Savannah
Aldora, Barnesville

Iowa
Sioux City

Illinois
Des Plains, Elk Grove, Elk Grove Village, Mt Prospect
Blue Island, Calumet Park, Chicago (southwest), Evergreen Park, Merrionette Park
Dixmoor, Dolton, Harvey, Phoenix, Riverdale, South Holland
Lemont
Robinson
Tuscola
Lawrenceville
East Alton, Hartford, Rosewood Heights, Roxana, South RoOana, Wood River
Tonti (near Salem)
Joliet, Rockdale

Indiana
B-cwnsberg
East Chicago, Hammond, Whiting

Kansas
El Dorado
Arkansas City
Greensburg (near Mullinville)
McPherson
Coffeyville
Hutchinson
Grant (near Valley Center)
Kansas City

Kentucky
Ashland, Cattletsburg

Louisiana
Shreveport
Lake Charles
Sulphur
Prien
West Hackberry
Baton Rouge, Port Allen
Baker, Baton Rouge, Scotlandville
Weeks Island
Bayou Choctaw
Plaquemine, Seymourville
Ibervilee Country (near Carville)
Gretna, Harvey, Terrytown, Timberlane, Belle Chasse
Jefferson
Jennings
Port Sulphur
Chalmette, Meraux, Violet
Hahnville, New Sarpy, Norco
Destrehan, Lone Star, Luling, New Sarpy, St Rose
Good Hope
Convent, St James, Union
Garyville, Reserve
Opelousas
Bayou Vista, Berwick, Morgan City, Patterson
LOOP (offshore)

Massachusetts
Ludlow
Braintree, Quincy
Boston, Chelsea, Cambridge, Everett, Somerville

Maryland
Edgemere, Sparrow's Point

Maine
Portland, South Portland, Westbrook

Michigan
Lincoln (near Harrison)
Alma, St Louis
Marysville, Port Huron, (and Sarnia, Ontario)
Dearborn, Detroit, Ecorse, Melvindale, River Rouge
Livonia, Farmington, Farmington Hills

Minnesota
Columbia Heights, Fridley, Hilltop, New Brighton, St Anthony, Spring Lake Park, Brooklyn Center, Minneapolis
Empire

Missouri
Independence, Sugar Creek

Misisisippi
Liberty
Collins
Gulfport
Pascagoula
Purvis
Vicksburg

Montana
Fallon Country (near Baker and Plevna)
Cut Bank
Billings
Laurel

North Dakota
Mandan

North Carolina
Pine Valley, Wilmington, Winter Park

New Hampshire
Newington, Portsmouth

New Jersey
Burlington, Florence-Roebling
Deptford, Greenloch, National Park, Paulsboro, Thorofare, Wenomah, Westville, Woodbury, Woodbury Heights
Avenal, Laurence Harbor, Perth Amboy, Sayreville, South Amboy, Woodbridge
Eatontown, Little Silver, Long Branch, Monmouth Beach, Ocean Port, Shrewsbury, West Long Branch
Atlantic Highlands, Highlands, Middletown
Carteret, Elizabeth, Linden

New Mexico
Lea country (near Eunice)
Prewitt (near Thoreau)
Kirtland

New York
Albany
Bronx, Queens
Endicott, Endwell, Johnson City
Buffalo city, Sloan
Brooklyn, Manhattan
Irondequiot, Rochester
Oswego
Ogdensburg

Ohio
Lima
Cleveland, Cleveland Heights, East Cleveland
Addyson, Cleves, Hoover, N. Bend
Harbor View, Oregon
Campbell, Youngstown
Canton, Myers Lake, North Canton

Oklahoma
Ardmore
Clemscot (near Tatmus)
Creek Country (near Drumright)
Arapahoe
Enid
Wynnewood
Ponca City
Cushing
Tulsa

Oregon
Portland

Pennsylania
Avalon, Bellevue, Ben Avon, Ben Avon Heights, Coraopolis, Crafton, Emsworth, Glenfield, Ingram, Kennedy, Kilbuck, McKees Rocks, Neville, Osborne, Pennsbury Village, Pittsburg, Stowe, Thornsbury
Kenhorst, Mohnton, Mt Penn, Reading, Shillington, Sinking Spring, West Lawn, West Reading, Wyomissing, Wyomissing Hills
Chester Springs, West Pikeland
Aldan, Clifton Heights, Collingdale, Colwyn, Darby, East Lansdowne, Folcroft, Glenolden, Lansdowne, Norwood, Prospect Park, Sharon Hill, Yeaden; Philadelphia: Philadelphia
Lower Chichester, Marcus Hook, Trainer
Bethlehem, Freemansburg, Hellertown, Middletown
Belvidere
Philadelphia
Avondale-Moorland, Charleston, Dorchester Terrace-Brentwood, Wando Woods

Tennessee
Chatanooga, Ridgeside
Memphis

Texas
Sweeny
Bryan Mound
Quintana, Surfside Beach
Point Comfort
Brownsville
Cameron County (near Port Isabel)
Crane
El Paso
Fort Bliss
Highland Bayou, La Marque, Texas City
Galveston, Jamaica Beach
Longview
Houston
Houston, Pasadena, South Houston
Baytown
Channelview
Deer Park, W Lomax
Big Spring
Borger, Phillips
Beaumont
Griffing Park, Groves, Nederland, Port Arthur, Port Neches
Port Arthur
Big Hill
Sabine
Premont
Zunkerville
Three Rivers
Midland
Spraberry
Sunray
Corpus Christi
Agua Dulce
Coyanosa
Amarillo
Aransas Pass, Ingleside
Tyler
Abilene
Austin
Kermit

Utah
North Salt Lake, Val Verda, Woods Cross
Salt Lake City

Virginia
Yorktown

Hampton, Newport News
Portsmouth, Norfolk

Washington
Port Angeles
Seattle
North City-Ridgecrest, Richmond Beach-Innis Arden, Richmond Highlands, Sheridan Beach
Tacoma
Anacortes
Edmonds, Everett, Fairmont-Intercity, Mulkilteo
Ferndale

Wisconsin
Allouez, Green Bay
Parkland (near Superior Village & Poplar)

West Virginia
Fairview
Granville, Osage, Morgantown, Star City, Westover

Wyoming
Rawlins, Sinclair
Casper, Evansville
Newcastle

(Note: Some targets receive multiple weapons.)

The U.S. Economy After Small Nuclear Attacks

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